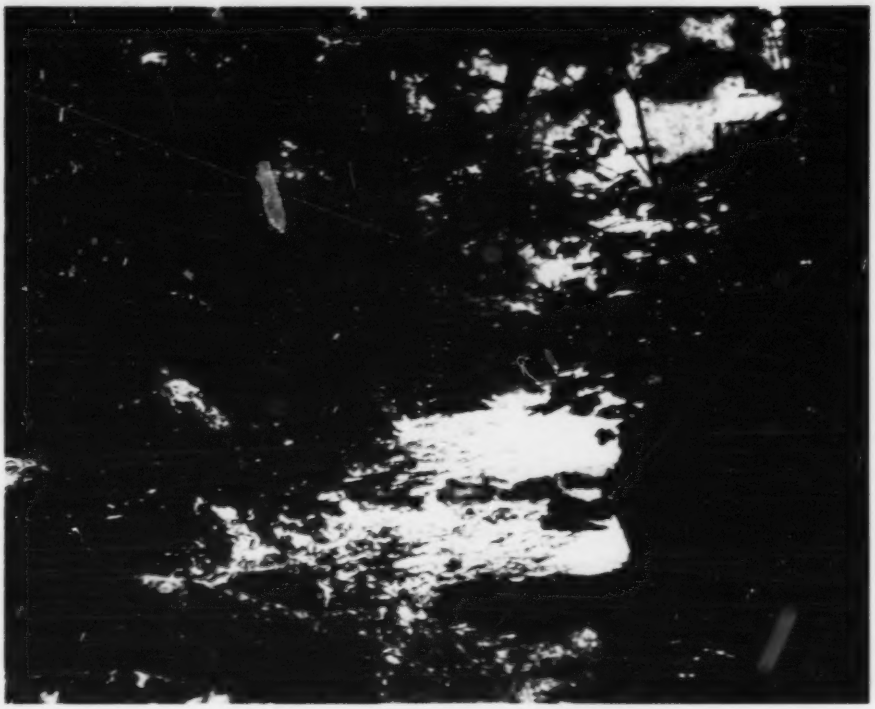
Federal/Provincial Research and Monitoring Coordinating Committee (RMCC)



THE 1990 CANADIAN LONG-RANGE TRANSPORT OF AIR POLLUTANTS AND ACID DEPOSITION ASSESSMENT REPORT

Part 2

EMISSIONS AND CONTROLS

1990

ACID RAIN

PLUIES ACIDES

Province of British Columbia
Ministry of Environment and Parks

Gouvernement du Québec
Ministère de l'Environnement

Alberta
ENVIRONMENT

New Brunswick
Department of Municipal Affairs and Environment

Saskatchewan
Environment and Public Safety

Community & Cultural Affairs

Manitoba
Environment and Workplace Safety and Health

Nova Scotia
Department of the Environment

Environment Ontario

Province of Newfoundland
Department of the Environment

Canada

FEDERAL/PROVINCIAL

RESEARCH AND MONITORING

COORDINATING COMITTEE (RMCC)

THE 1990 CANADIAN LONG-RANGE TRANSPORT OF AIR POLLUTANTS AND ACID DEPOSITION ASSESSMENT REPORT

PART 2

EMISSIONS AND CONTROLS

1990

91-04762/

Principal Author:

Pierre Pinault
Industrial Programs Branch
Environment Canada

Contributors:

Leo Buffa
Industrial Programs Branch

Patrick Finlay
Industrial Programs Branch

Beverly Hobby
Legal Services

Bernard Madé
Industrial Programs Branch

Arthur Sheffield
Management and Emergencies Branch

Frank Vena
Management and Emergencies Branch

Sherri Watson
Industrial Programs Branch

Staff from Environment Canada's Headquarters and Regional Offices provided assistance and guidance to the author. The text was reviewed by readers from Energy, Mines and Resources Canada and from various provincial governments. Stephan Mitchell was also of able assistance to the author.

TABLE OF CONTENTS

SECTION	PAGE#
LIST OF TABLES	2-iv
LIST OF FIGURES	2-v
2.1 SUMMARY	2-1
2.2 INTRODUCTION	2-3
2.3 CANADIAN EMISSIONS, 1970-85	2-8
2.3.1 SO_2	2-8
2.3.2 NO_x	2-9
2.3.3 HCs AND VOCs	2-10
2.3.4 COMPARISON OF EMISSIONS IN CANADA AND THE UNITED STATES	2-10
2.4 JURISDICTIONAL ASPECTS OF CANADIAN ENVIRONMENTAL ACTIONS	2-13
2.4.1 DOMESTIC	2-13
2.4.2 INTERNATIONAL	2-13
2.5 THE CANADIAN SO_2 CONTROL PROGRAM	2-15
2.5.1 NON-FERROUS SMELTERS	2-18
2.5.1.1 ELEMENTS OF THE CURRENT PROGRAM	2-18
2.5.1.2 INDUSTRY RESPONSE	2-21
2.5.1.2.1 Inco Ltd., Thompson, Manitoba	2-21
2.5.1.2.2 Hudson Bay Mining and Smelting, Flin Flon, Manitoba	2-21
2.5.1.2.3 Inco Ltd., Copper Cliff, Ontario	2-21
2.5.1.2.4 Falconbridge Ltd., Falconbridge, Ontario	2-22
2.5.1.2.5 Noranda Minerals Inc., Noranda (Horne), Quebec	2-22
2.5.1.2.6 Noranda Minerals Inc., Murdochville, Quebec	2-23
2.5.1.2.7 Financial Commitments at Canadian Smelters	2-23
2.5.2 ELECTRIC UTILITIES	2-23
2.5.2.1 ONTARIO HYDRO	2-23
2.5.2.2 NEW BRUNSWICK POWER	2-24
2.5.2.3 NOVA SCOTIA POWER CORPORATION	2-27

SECTION	PAGE#
2.5.2.4 NEWFOUNDLAND UTILITIES	2-27
2.5.2.5 PRINCE EDWARD ISLAND	2-28
2.5.3 OTHER SO_2 SOURCES	2-28
2.5.3.1 ONTARIO	2-28
2.5.3.2 QUEBEC	2-29
2.5.3.3 NEW BRUNSWICK	2-29
2.5.3.4 NOVA SCOTIA	2-30
2.5.4 SO_2 CONTROL OPTIONS	2-30
2.6 THE CANADIAN NO_x - VOCs CONTROL PROGRAM	2-33
2.6.1 PRE-1985 INITIATIVES	2-33
2.6.2 CURRENT NO_x-VOCs CONTROL INITIATIVES	2-33
2.6.2.1 MOBILE SOURCES	2-35
2.6.2.2 STATIONARY SOURCES	2-38
2.6.3 NO_x AND VOCs CONTROL OPTIONS	2-38
2.7 EMISSIONS AND CONTROL MEASURES IN THE 1990s	2-41
2.7.1 OVERVIEW OF EMISSION TRENDS	2-41
2.7.2 PROJECTED EMISSIONS IN CANADA	2-41
2.7.2.1 PROJECTED SO_2 EMISSIONS	2-42
2.7.2.2 PROJECTED NO_x EMISSIONS	2-43
2.7.2.3 PROJECTED VOCs EMISSIONS	2-44
2.8 FUTURE DIRECTIONS	2-46
APPENDICES	2-48
APPENDIX 2A1 SUPPLEMENTARY DATA TABLES	2-49
APPENDIX 2A2 SO_2 CONTROL TECHNOLOGIES	2-59
2A2.1 NON-FERROUS SMELTERS	2-59
2A2.1.2 REMOVAL OF SO_2 FROM EXHAUST GASES	2-59
2A2.2 POWER PLANTS AND BOILERS	2-60
2A2.2.1 COAL CLEANING	2-60
2A2.2.2 CONTROL OF SO_2 DURING AND AFTER COMBUSTION	2-62

SECTION	PAGE#
APPENDIX 2A3 CONTROL MEASURES FOR NO_x AND VOCs	2-66
2A3.1 MOBILE SOURCES	2-66
2A3.2 BOILERS	2-67
2A3.3 OTHER STATIONARY COMBUSTION SOURCES	2-69
2A3.4 STATIONARY VOCs SOURCES	2-70
APPENDIX 2A4 MAP OF SELECTED MONITORING SITES IN EASTERN CANADA	2-72
REFERENCES	2-74

LIST OF TABLES

TABLE#		PAGE#
2.5.1	Eastern Canada SO_2 Emissions Reductions and Objectives	2-17
2.5.2	Primary Metals Smelters in Eastern Canada: Kilotonnes of SO_2 Emissions per Kilotonne of Metal Production and Metal Production in Kilotonnes	2-19
2.5.3	Provincial Regulations Enacted to Meet the 1994 SO_2 Reduction Target	2-20
2.5.4	Capital Costs of SO_2 Controls at Non-Ferrous Smelters	2-23
2.5.5	Ontario Hydro Acid Gas Emissions and Regulatory Limits	2-25
2.5.6	New Brunswick Power SO_2 Emissions	2-26
2.5.7	Summary of SO_2 Control Measures	2-31
2.6.1	Summary of Canadian Vehicle Emissions Standards	2-34
2.6.2	Proposed Vehicle Emissions Standards	2-36
2.6.3	Summary of NO_x & VOCs Control Measures	2-39
	Appendix 2A1	
2.3.1	SO_2 Emissions in Canada by Province	2-50
2.3.2	NO_x Emissions in Canada by Province	2-51
2.3.3	HC Emissions in Canada by Province	2-52
2.7.1	SO_2: Projected Emissions in Canada by Province	2-53
2.7.2	SO_2: Projected Emissions in Canada by Sector	2-54
2.7.3	NO_x: Projected Emissions in Canada by Province	2-55
2.7.4	NO_x: Projected Emissions in Canada by Sector	2-56
2.7.5	VOCs: Projected Emissions in Canada by Province	2-57
2.7.6	VOCs: Projected Emissions in Canada by Sector	2-58

LIST OF FIGURES

FIGURE#		PAGE#
2.1.1	SO_2 Emissions in Canada, 1975-2000	2-2
2.2.1	North American SO_2 Emissions in 1985	2-4
2.3.1	SO_2 Emissions in Canada by Region, 1970-1985	2-8
2.3.2	NO_x Emissions in Canada by Region, 1970-1985	2-9
2.3.3	Hydrocarbon Emissions in Canada by Region, 1970-1985	2-10
2.3.4	SO_2 and NO_x Emissions in Canada and United States	2-11
2.3.5	Comparison of Canadian and United States NO_x and VOC Emissions, 1985	2-12
2.7.1	Canadian Emission Trends: SO_2, NO_x and VOCs	2-41
2.7.2	Projected SO_2 Emissions by Region, 1985-2005	2-42
2.7.3	Projected SO_2 Emissions by Sector, 1985-2005	2-43
2.7.4	Projected NO_x Emissions by Region, 1985-2005	2-43
2.7.5	Projected NO_x Emissions by Sector, 1985-2005	2-44
2.7.6	Projected VOCs Emissions by Region, 1985-2005	2-44
2.7.7	Projected VOCs Emissions by Sector, 1985-2005	2-45

2.1 SUMMARY

Concern about the long-range transport of air pollutants (LRTAP) in Canada has focused on the damage caused by acid rain and ground level ozone. In response, the federal and provincial governments have developed a cooperative approach to domestic emissions control which meets national goals while respecting provincial authority related to environmental protection matters and the need for regional flexibility. Canada also recognizes the transboundary nature of LRTAP and has therefore continued to promote and participate in both bilateral and international agreements to complement its actions at home.

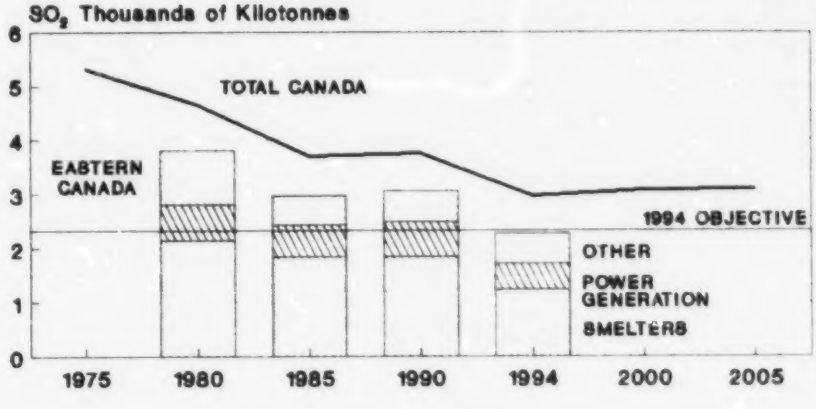
The effects of acid deposition are most severe in eastern Canada, mainly caused by sulphur dioxide (SO_2) emitted from eastern Canadian smelters and power plants, and by SO_2 releases from power plants in the midwestern United States.

In 1985 the Eastern Canadian SO_2 Control Program was established when the Federal Government and the seven eastern provinces agreed to cut annual SO_2 emissions by 50 percent by 1994. In addition, the federal government has been supporting the development and demonstration of technologies which reduce SO_2 emissions at their source, and both federal and provincial governments have made funds available to industry to implement controls.

The program requires that the total annual sulphur dioxide emissions from the seven eastern provinces be reduced to 2300 kilotonnes by the end of 1994, a decrease of 50 percent from the 1980 base case (Fig.2.1.1). Each province agreed to a specific overall reduction targets and, in general, control efforts have been directed towards major SO_2 sources, where the largest and most cost-effective reductions can be achieved. These include the non-ferrous metals smelters and power plants (mainly those burning coal) which produced about 50 and 20 per cent, respectively, of Canada's SO_2 emissions in 1985. As a result, six large copper, nickel and zinc smelters,one iron ore sintering plant and three provincial electrical utilities are responsible for implementing the major portion of eastern Canada's SO_2 control program. The 1987 Eastern Canadian SO_2 emissions, (the most recent estimates available) were 3,066 kilotonnes.

Another LRTAP pollutant of concern in Canada is ground level ozone (smog) which can have serious health and agricultural effects. It is produced in the lower atmosphere from photochemical reactions involving NO_x and volatile organic compounds (VOCs). The Canadian Council of Ministers of the Environment (CCME) has directed that a national Management Plan for solving the NO_x-VOC-ozone problem be developed by fall of 1990. A draft of this plan was released for public comment in March 1990. It will address the reduction of NO_x and VOC emissions from a broad spectrum of sources, including automobiles, power plants, industrial and commercial boilers, stationary piston engines and combustion turbines, as well as vapour losses when gasoline is transported, stored and consumed.

Fig. 2.1.1: SO_2 Emissions In Canada
1975 - 2000



2.2 INTRODUCTION

Canadian concern about air quality and air pollution was heightened during the 1960s, a period of rapid industrial expansion and urbanization. Growing environmentalism led to the passing of Canada's Clean Air Act in 1971 and to the creation of the federal Department of the Environment in the same year. A number of provinces also created and expanded environmental agencies at about the same time. In the early 1970s, the main air pollution concerns were related to human health and atmospheric visibility. Ambient air quality objectives for sulphur dioxide (SO_2), nitrogen oxides (NO_x), ozone and particulates were developed. Major pollution sources were regulated to reduce ambient ground level concentrations to acceptable standards, often using dilution or dispersion techniques to meet these requirements. Canada also adopted tail pipe vehicle emission standards, and specific regulations were enacted to deal with toxic pollutants such as lead. Gradually, vehicle emission standards were tightened and voluntary fuel efficiency improvements were introduced by the automobile industry. As well, efforts to improve mineral processing and smelting techniques at various major non-ferrous smelters lead to some reductions in SO_2 emissions.

Despite some improvements in air quality, particularly in SO_2 levels, by the end of the 1970s newer and broader concerns such as acid rain had been documented.

Acid Rain

Acid rain, as the phenomenon is commonly known, occurs when SO_2 and NO_x are converted to sulphuric and nitric acid, and deposited in a wet form in precipitation or in a dry form as particles or by the absorption of the gases. In eastern Canada, much of the acid rain problem is the result of SO_2 emitted by eastern Canadian smelters and power plants, and by power plants in the north-central United States. Figure 2.2.1 is a map of SO_2 emissions sources in North America. NO_x emissions, although a contributing factor to the acidity of precipitation, are not considered to be the major cause of acidification of surface waters in eastern Canada.

Much of eastern Canada and parts of western and northern Canada have soils and rocks that are sensitive to acidic deposition. These regions are naturally deficient in the alkaline minerals which serve to neutralize acidic pollutants. In eastern Canada this sensitivity, combined with long term deposition has led to the widespread acidification of lakes. Acidification has harmful effects on fish and other aquatic life. It can cause damages to soils and forests, and accelerates corrosion on buildings and structures. Some studies indicate that the nitrogen and sulphur compounds in the atmosphere can affect human health.

In order to reduce the effects of acid, reductions in the emissions of acid forming pollutants are required. The role of long distance transport of atmospheric pollutants has been recognized, and, it is known that acidification in Canada is also due to pollutants

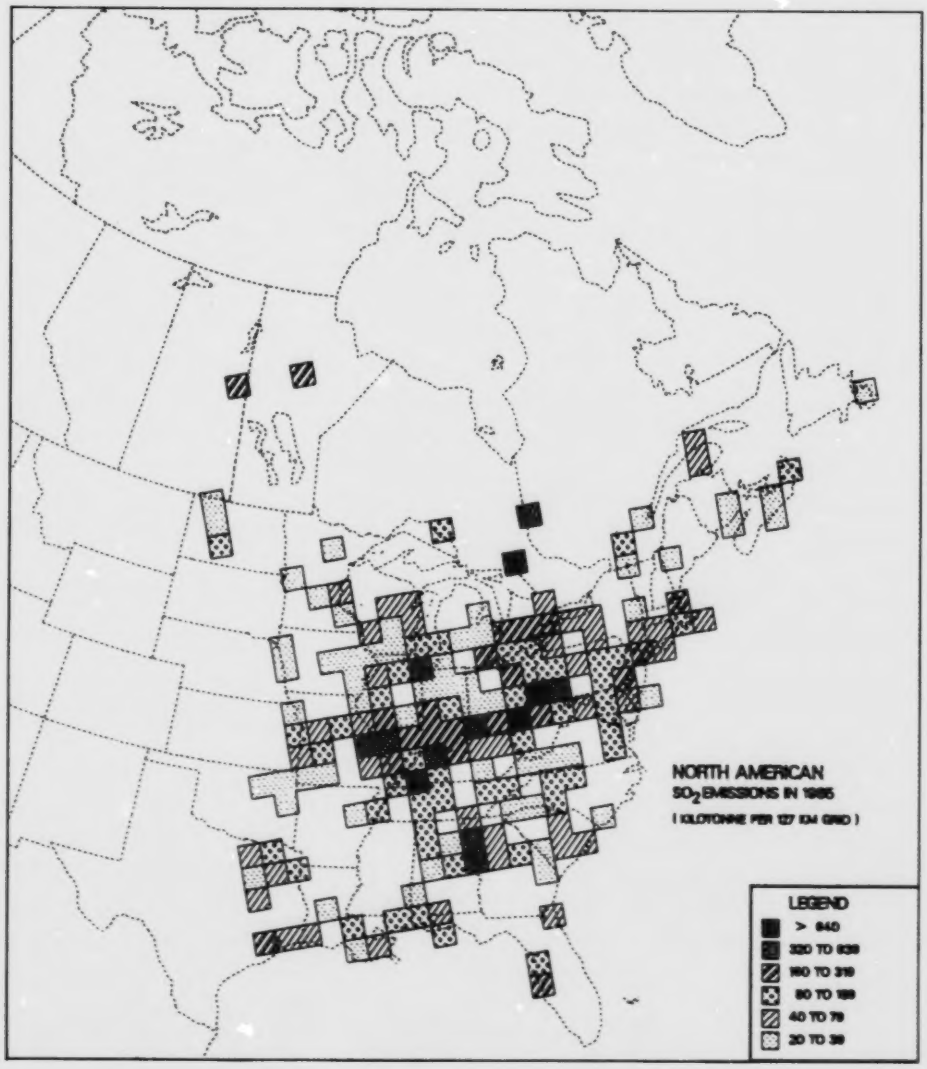


Figure 2.2.1: North American SO_2 Emissions in 1985 (kilotonne per 127 km grid)

being carried over long distances by prevailing winds from the United States. Similarly, depending on air movements, emissions from Canada flow into the northeastern United States.

In 1980, Canada and United States signed a Memorandum of Intent Concerning Transboundary Air Pollution. Among other things, the agreement set the stage for continued acid rain research in both countries, in order to expand and verify knowledge of the mechanisms and effects of acidification.

Canadian research at that time indicated that reducing deposition of wet sulphate to less than 20 kilograms per hectare per year in eastern Canada would be sufficient to protect moderately sensitive lakes. Research also indicated that to achieve this goal, a 50% reduction in SO_2 emissions in eastern Canada and in transboundary flows of SO_2 from the United States, would be required (MOI, 1983).

In 1987 and 1988, the seven eastern provinces - Manitoba, Ontario, Quebec, New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland - signed formal agreements with the federal government to reduce emissions by 50 percent (2300 kilotonnes per year) by 1994. These agreements constitute the eastern Canada acid rain control program.

In western Canada, deposition of acid rain is much less than in the East. Nonetheless, in 1980, the federal government and the governments of Manitoba, Saskatchewan, Alberta, British Columbia and later, the Northwest Territories, recognized the potential of acid rain to cause harm in some regions. As a result, a continuing program to monitor and study the effects of acid rain on western ecosystems was established.

To address the transboundary flow issue, Canada has pursued its acid rain agenda on the international stage. In 1979, Canada signed the Convention on the Long Range Transport of Air Pollutants (LRTAP) under the aegis of the United Nations Economic Commission for Europe (ECE). Canada subsequently signed the ECE protocol on SO_2 in 1985; this protocol requiring a 30 percent reduction in SO_2 from 1980 emission levels by 1993. Canada has also engaged in a dialogue with the United States in order to encourage that country to initiate its own acid rain control program and reduce its transboundary flows of SO_2 into Canada, and to conclude a bilateral accord on acid rain. The year 1990 marks the mid-point of the Canadian control program and the end of a decade of intense work on the acid rain problem.

<u>NO_x, VOCs and Ozone</u>

While acidification from SO_2 has been one of Canada's major air pollution problems over the past decade, during that same period of time, urban smog in heavily populated and industrialized areas has also emerged as a broad regional concern. One of the main components of smog is ozone.

Ozone is a so-called secondary pollutant in that it is not emitted directly out of a smokestack or exhaust pipe but is formed in the atmosphere. NO_x and volatile organic compounds (VOCs), released from automobiles or smokestacks undergo chemical reactions with oxygen. In the presence of sunlight and result in the formation of elevated concentrations of ground level ozone. Heat speeds up the reaction between the chemical pollutants involved, and consequently the highest concentrations of ozone are experienced during the summer months.

Ground level ozone can cause damage to the human respiratory system, to agricultural crops, trees and other vegetation. During the summer months, about one half of the Canadian population is exposed to ozone levels which exceed the national one hour standard of 82 parts per billion, above which negative health effects are known to occur. (Dann, 1989; Lippman, 1989). Peak concentrations can be more than twice this value at times. There are also measurements of high ozone concentrations in many rural areas of Canada.

NO_x and VOCs are also pollutants in their own right. In Canada, although not the major damage due to acid rain, NO_x emissions do contribute to the problem. There have also been occasions when NO_x emissions (which are measured in Canada as NO_2) have exceeded the one hour or 24 hour maximum levels (Dann, 1989). Several VOCs are also on the Priority Substance List of the Canadian Environmental Protection Act and are thought to be toxic. If found to be toxic these compounds will be subject to regulation.

Canada's federal and provincial governments have developed a management plan to address ground level ozone through the control of NO_x and VOCs. Stringent regulations to control emissions from internal combustion engines and from fuels will be put in place within the next five years. Vehicle inspection and maintenance programs will be implemented by 1992 in provinces where ground level ozone problems occur.

The Canadian ozone management plan will reduce VOCs emissions by at least 30 percent in key ozone problem areas and the reduction of peak summertime ozone levels is estimated to range from 15 to 35 percent in most areas of concern. In the areas of primary concern, it is estimated that there will be a 30 to 75 percent reduction in the number of hours with ozone levels above the maximum acceptable concentration.

Since both ground level ozone and its precursor pollutants can be transported over long distances in the lower atmosphere, the smog problem also has a major transboundary element. A significant portion of Canadian ozone in high ambient level areas originates in the United States, and Canadian source emissions occasionally flow south.

Transboundary NO_x pollution was the subject of an international protocol developed under the auspices of the Economic Commission for Europe (ECE) that was signed in Sofia, Bulgaria, on November 1, 1988 (For a list of Canada's major international air pollution control commitments, see section 2.4.2.). The primary provision of this protocol is a

freeze in NO_x emissions at 1987 levels by 1994. The protocol also commits signatories to implementing emission standards for major new combustion sources, based on best available technology economically feasible. The Canadian ozone management plan will ensure that Canada's basic obligations under the ECE protocol are met. The plan will result in decreases of transboundary flows to the United States of 25 to 35 percent, in those areas experiencing significant transboundary flows.

2.3 CANADIAN EMISSIONS, 1970-85

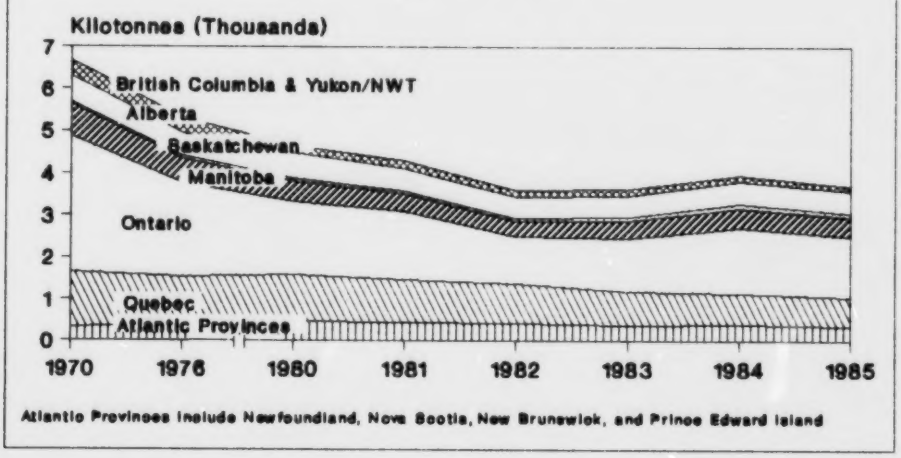
This section provides a perspective on Canadian emissions of SO_2, NO_x and hydrocarbons (HC) before the Canadian Acid Rain Control Program was put in place (HC emissions are a broad category which includes VOCs). It also compares emissions of these pollutants from Canada and the United States.

2.3.1 SO_2

Figure 2.3.1 shows SO_2 emissions in each region of Canada for the period 1970 to 1985. During that time, as the result of early control programs, SO_2 emissions declined from 6.7 million tonnes to 3.7 million tonnes, a 45 percent reduction.

Numerical data for this and other figures in the main text are presented in tables in Appendix 2A1.]

Fig. 2.3.1: SO_2 Emissions in Canada By Region 1970 - 1985



The decline in SO_2 emissions from 1970 to 1985 was due mostly to reductions at some non-ferrous metals smelters in New Brunswick, Quebec, Ontario and Manitoba, and to some reduction of coal use in Ontario as a result of that province's growing nuclear program. Reductions in British Columbia were due to the increased control of emissions from natural gas processing. In Alberta, despite a substantial expansion of coal-based electricity production, SO_2 emissions have not significantly increased. This is largely due to the burning of very low sulphur coal and to better sulphur containment controls in the natural gas industry.

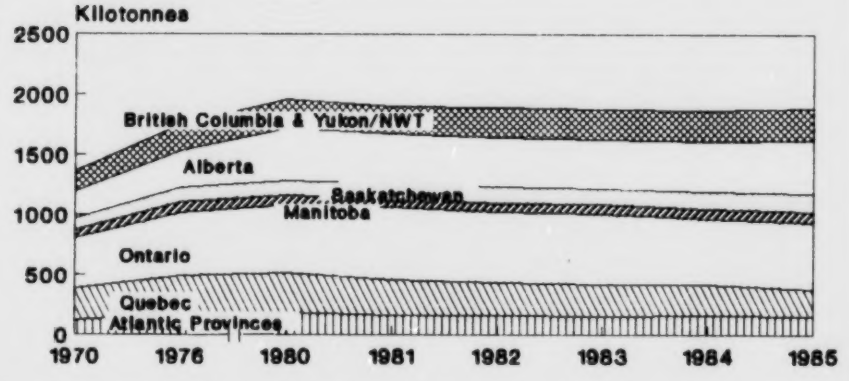
2.3.2 NO_x

In this report, unless otherwise noted, the tonnages of NO_x emissions are expressed as NO_2, which is used to represent all oxides of nitrogen.

Figure 2.3.2 illustrates the trend by region for Canadian NO_x emissions in the period 1970 to 1985. In this period, NO_x emissions increased from about 1.4 million tonnes to about 2 million tonnes, despite the enactment in 1977 of emission standards for light-duty vehicles, which are by far the largest source of NO_x.

In 1980, transportation sources accounted for 69 percent of NO_x emissions. The overall increase in NO_x emissions from 1970 to 1985 can be attributed to three main factors: a significant expansion in the total number of vehicles; a significant lag between enactment of vehicle standards and their effects, due to slow vehicle inventory turn-over; and greater emissions from other NO_x sources, notably fuel combustion in boilers and furnaces.

Fig. 2.3.2: NO_x Emissions in Canada By Region 1970 - 1985



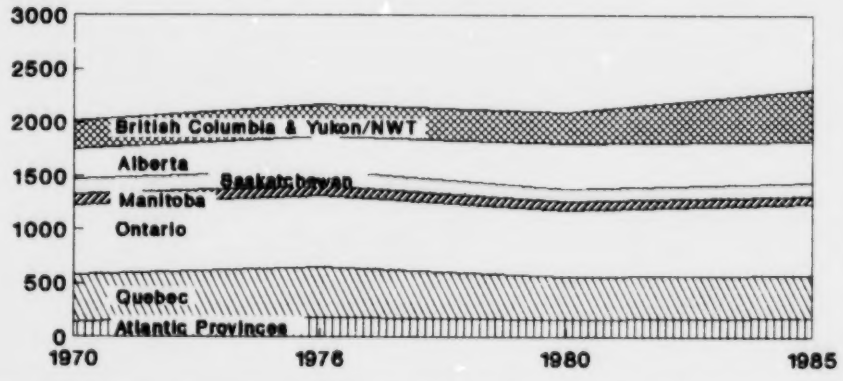
Atlantic Provinces include Newfoundland, Nova Scotia, New Brunswick, and Prince Edward Island

The trend towards higher emissions is especially evident in the more populated provinces: Ontario, Quebec and British Columbia. In Alberta, reciprocating natural gas compressors are a significant additional source of NO_x emissions, and largely account for the increases in that province.

2.3.3 HCs AND VOCs

As illustrated in Figure 2.3.3, total HC emissions increased 15 percent from 1970 to 1985, from 2.0 million tonnes to about 2.3 million tonnes. In that time, the principal sources of Canadian emissions were (and continue to be) gasoline-powered motor vehicles, the gasoline fuel cycle, refineries, petrochemical plants, the application of surface coatings, solvent use, and the natural gas fuel cycle (the latter is mainly responsible for methane emissions). Emissions are greatest in the more industrialized provinces of Ontario, Quebec, Alberta and British Columbia. In 1985, the VOCs portion of HC emissions was 78 percent, although this ratio may not apply exactly in other years. It should be noted that early inventories of hydrocarbon emissions were commonly determined as total hydrocarbons less methane, and the mass rate of emissions was expressed as methane equivalent. Total hydrocarbon emissions are presently segregated into non-photochemically and photochemically reactive compounds; it is these latter which are termed volatile organic compounds. This distinction began with the 1985 inventory.

Fig. 2.3.3: HC Emissions In Canada by Region
1970 - 1985

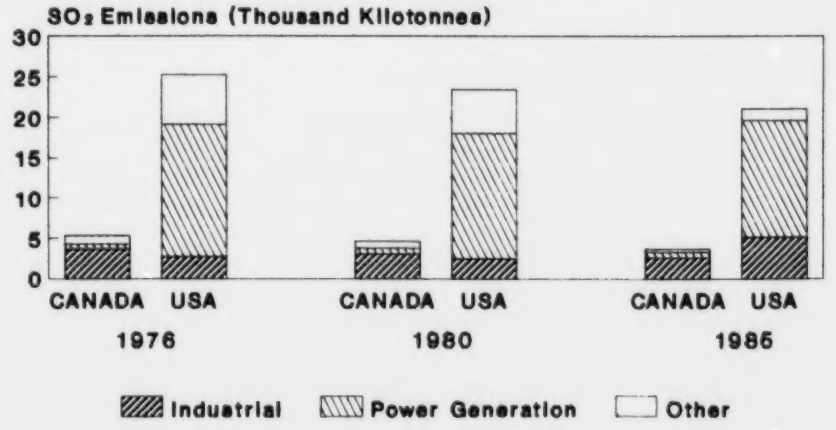


Atlantic Provinces include Newfoundland, Nova Scotia, New Brunswick, and Prince Edward Island

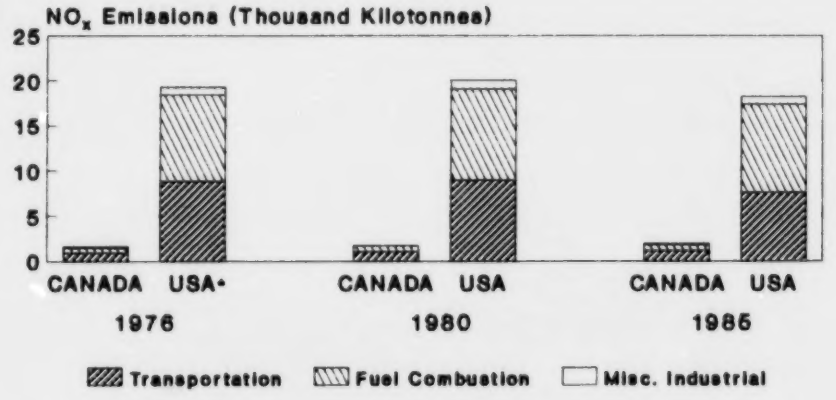
2.3.4 COMPARISON OF EMISSIONS IN CANADA AND THE UNITED STATES

To put Canadian pollutant emissions in a North American context, Figure 2.3.4 provides a comparison of Canadian and United States emissions of SO_2 and NO_x. The figure also shows the reductions made in SO_2 in both countries in the period from 1980 to 1985.

Fig. 2.3.4: Canadian Emissions In The North American Context
1976 - 1985



Industrial includes Metals Smelting



* 1976 U.S. Emissions shown are taken from 1975 estimates

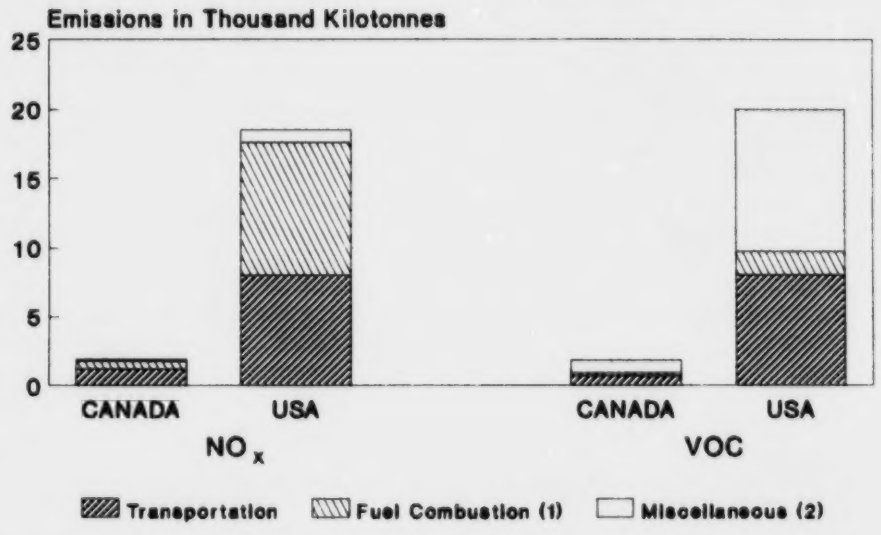
VOCs are not presented graphically because of the lack of data and due to the fact that prior to 1985, VOCs were not singled out as a separate class of emissions.

In 1985, the most recent year for which comparable inventories exist, Canadian emissions of SO_2 were equivalent to about 18 percent of those in the United States where 70 percent of SO_2 emissions in 1985 were from power plants; in Canada this proportion was only 20 percent.

Canadian emissions of SO_2 originate largely at non-ferrous smelters that accounted for nearly half of all SO_2 emissions in 1985.

As illustrated in Figure 2.3.5, Canadian emissions of NO_x and VOCs were only about 10 percent of the United States totals. NO_x emissions are also different in source composition. Whereas 63 percent of Canadian NO_x emissions are attributable to vehicles, in the United States it is only 47 percent. This difference reflects a greater proportion of power plant-produced NO_x in the United States.

Fig. 2.3.5: Comparison of NO_x and VOC, Canada and U.S. 1985



(1) Fuel Combustion includes power generation.
(2) Misc. includes mainly industrial sources such as solvent use and fuel production and marketing.

2.4 JURISDICTIONAL ASPECTS OF CANADIAN ENVIRONMENTAL ACTIONS

2.4.1 DOMESTIC

The Canadian Constitution, which assigns legislative responsibilities to the federal and provincial governments, does not list the environment as a separate subject. Consequently, there are many areas within the category of environment where federal and provincial jurisdiction overlap. Atmospheric pollution is one of these. The Canadian approach to addressing matters of air pollution is a shared responsibility which entails the cooperation of federal and provincial governments, and requires that action be taken by each level of government.

In March 1984, the Minister of Environment of the seven Eastern Canadian provinces and the Federal Minister of Environment agreed in principle to reduce emissions by about 50 percent from the 1980 base by the end of 1994. The 50 percent reduction was based on the fact that current deposition values were up to twice as much as the 20 kg/ha/yr wet sulphate target loading that had been accepted as an environmental goal. The provinces used a screening model as a guide in developing a least cost control program which led to specific reduction allocations by provinces. The provinces then, undertook to establish the required control programs for industries within their own jurisdictions. The control programs that were developed became the basis of federal provincial agreements.

The success of the eastern Canada in acid rain control program has reinforced the pattern of federal-provincial cooperation, and provides a useful model which is being used to address other environmental issues.

2.4.2 INTERNATIONAL

A number of important legal principles and agreements are the basis of Canada's efforts to address the transboundary aspects of acid rain and other types of atmospheric pollution.

Article 74 of the Charter of the United Nations enshrines the general principle of good neighbourliness in international relations. This principle is exemplified by the maxim "sic utere tuo ut alienum non laedus", "use your property so not to injure others". This doctrine has been affirmed by the International Court of Justice (I.J.C., 1949), and has evolved into three tenets of international law: that nation states have an obligation to avoid doing transboundary harm to other states, that environmental harm may be wrongful, and that victim nation states have the legal right to insist on the prevention and abatement of such harm. These principles are confirmed in the Declaration of Principles adopted by the United Nations 1972 Conference on the Environment, also known as the Stockholm Declaration. This Declaration was endorsed by Canada, the United States, and an overwhelming majority of other member states.

Canada is a signatory to a number of international legal instruments which are based upon the above principles. These include the United Nations Economic Commission for Europe Convention on Long-Range Transboundary Air Pollutants, the Helsinki SO_2 Protocol, the Sofia NO_x Protocol, the Vienna Convention on the Protection of the Ozone Layer and the Montreal Protocol for the Protection of the Ozone Layer.

These same principles are at the heart of Canadian efforts to undertake a joint program with the United States for the abatement of acid rain. Many areas of Canada are suffering environmental damage as a result of acidic emissions that originate in the United States. At the same time, Canadian emissions can also contribute to acid deposition in the United States. It is only through effective international cooperation that the transboundary effects of acid rain can be solved.

2.5 THE CANADIAN SO_2 CONTROL PROGRAM

The Canadian SO_2 control program focuses on controlling major sources of emissions, in the seven eastern provinces. The main sources of SO_2 emissions in Canada are, in decreasing order of magnitude, non-ferrous smelters, coal-fired power plants, non-utility fuel combustion and other comparatively minor sources.

In 1985, metals smelting accounted for about half of Canada's SO_2 emissions. Power plants, mainly coal burning ones, accounted for 20 percent. Most SO_2 emissions were concentrated in Manitoba, Ontario, Quebec, New Brunswick and Nova Scotia. In Western Canada, Alberta, with its oil and gas industry and coal-fired power plants, was a significant emitter of SO_2.

The eastern Canadian provinces are targeting those emissions sources where the largest reductions can be most efficiently made. The agreements signed with each province establish annual limits on provincial SO_2 emissions, to be attained by 1994, as fallows:

- Ontario committed itself to an SO_2 emissions level of no more than 885 kilotonnes. The agreement included specific control regulations for four major sources of SO_2.

- Quebec agreed to meet its SO_2 total emissions target of no more than 600 kilotonnes by 1990, and to encourage alternative energy source use and conservation.

- Manitoba agreed to reduce its total SO_2 emissions to a target of no more than 550 kilotonnes.

- Nova Scotia committed itself to an SO_2 total emissions target of 204 kilotonnes. The province agreed to negotiate specific reductions for specific sources within the province.

- New Brunswick committed itself to an SO_2 total emissions target of 185 kilotonnes, and to negotiate specific reductions for major sources in the province in order to meet this target.

- Newfoundland agreed to reduce total SO_2 emissions to 45 kilotonnes, and to require state of the art SO_2 controls for new sources. In addition, the province committed itself to continue efforts to encourage alternative fuel use and energy conservation.

- Prince Edward Island agreed to a total SO_2 emissions target of 5 kilotonnes to encourage the use of alternative fuels and to conserve energy.

In general, the targets for action have been major primary metals producers (notably non-ferrous smelters) and thermal power plants. Table 2.5.1 summarizes the emissions baseline and objectives for each province, as well as the SO_2 emissions from the major source sectors.

The most recent year for which a comprehensive estimate of eastern Canadian SO_2 emissions is available is 1987. Total emissions in 1987 were 3066 kilotonnes, 32 percent less than the 1980 base case of 4516 kilotonnes. The 1980 base case used in the federal-provincial agreements reflect SO_2 emissions regulations already in place at the beginning of the program. The actual emissions in any year will be less than the maximum regulated value.

As has been noted, the metals industry is the major source of SO_2 emissions in Canada. Federal assistance has been provided to a number of smelters to support research and implement improved milling, beneficiation and smelting technologies. Federal support to smelters was channelled through the Department of Industry, Science and Technology's, Industry Research and Development Program (IRDP). This program has provided support for plant-scale research, and for the development and demonstration of technologies to reduce SO_2 emissions from smelters. Technologies for which support has been provided are described in Appendix 2A2 and include pyrrhotite rejection, the flash conversion of furnace matte, slag cleaning, zinc pressure leaching and the development of increased roasting. Total federal support for this program has been in excess of $13 million.

The federal government also undertook its own research to investigate new technologies to reduce SO_2 emissions and opportunities for fuel switching. Most control technology research and development and demonstration initiatives have been carried out under the Coal Utilization Program, administered by the Federal Department of Energy, Mines and Resources. Technologies which have been supported are described in Appendix 2A2 and include coal beneficiation, coal/water mixtures, sorbent injection, the development of advanced slagging combustors, fluidized bed combustion and coal gasification. Major projects include:

- fluidized bed combustion demonstrations at Chatham, New Brunswick and Summerside, Prince Edward Island;
- coal-water and coal-oil mixture combustion trials at Charlotte town, Prince Edward Island and Chatham, New Brunswick;
- projects in eastern and western Canada on coal beneficiation;
- demonstration of limestone and other sorbent injection with Ontario Hydro and Saskatchewan Power; and
- research on treatment and disposal of wastes from SO_2 removal technologies.

Table 2.5.1

Eastern Canada SO_2 Emissions Reductions and Objectives (kilotonnes)

	1980 baseline	1980 actual	1985	1987	1994 (projected)	1994 (committed target)
- Eastern Canada						
Primary Metals (2)	-	2148	1844	1839	1233	-
Power Generation	-	667	585	648	478	-
Total	4516	3819	2972	3066	2268	2300
- Newfoundland						
Power Generation	-	18	22	20	20	-
Total	59	56	43	51	45	45
- Prince Edward Island						
Total	6	4	2	3	3	5
- Nova Scotia						
Power Generation	-	125	130	135	147	-
Total	219	193	170	178	192	204
- New Brunswick						
Primary Metals	-	13	17	21	21	-
Power Generation	-	122	94	158	126	-
Total	215	220	138	216	185	185
- Quebec						
Primary Metals	-	641	502	463	311	-
Total	1085	1098	693	660	546	600
- Ontario						
Primary Metals	-	1031	899	816	461	-
Power Generation	-	398	337	332	152	-
Total	2194	1764	1457	1399	848	885
- Manitoba						
Primary Metals	-	463	459	539	440	-
Total	738	484	469	559	449	550

Notes:

- The 1980 base case emissions reflect existing regulations on emissions in place prior to the federal-provincial agreements.
- The 1994 objective is 2300 kilotonnes; the actual total of agreed-to objectives is 2474; 174 kilotonnes is to be allocated.
- Primary Metals includes non-ferrous smelters and iron ore mining and beneficiation, but excludes aluminum production.

The federal government has also actively supported major initiatives to improve energy efficiency and develop alternative energy forms. These include the Forest Industry Renewable Energy Program, a project to increase the use of forestry product wastes, research into wood burning residential heating equipment, and a major grant program to retrofit existing buildings to higher standards of insulation. In addition, the federal government has supported the extension of Canada's natural gas pipeline network to serve Quebec markets. While all these efforts have not been driven purely by environmental concerns, they have nonetheless fostered the twin objectives of reducing the consumption of sulphur-containing fuels and promoting energy efficiency.

2.5.1 NON-FERROUS SMELTERS

In Canada, non-ferrous metals smelters contributed in excess of 40 percent of the total SO_2 released in 1985. Table 2.5.2 summarizes SO_2 emissions per unit of metal production for non-ferrous smelters located in eastern Canada. Three of the smelters listed were not included in the acid rain program because they operated highly efficient process equipment to capture SO_2 and produce liquid SO_2 and sulphuric acid, and thus they emit only small amounts of SO_2 and offered no scope for further controls. These smelters are: Kidd Creek Mines at Timmins, Ontario; Canadian Electrolytic Zinc at Valleyfield, Quebec; and Brunswick Mining and Smelting at Belledune, New Brunswick.

2.5.1.1 ELEMENTS OF THE CURRENT PROGRAM

Specific large smelting facilities have been targeted as part of the federal-provincial program to reduce SO_2 emissions in eastern Canada, and a financial support program for research and development, capital and operating costs of containment measures has been implemented. The provincial regulatory approach set specific emission limits for each plant. These regulatory limits are summarized in Table 2.5.3.

- Manitoba: In 1988, Manitoba issued regulations which specify the total maximum annual emissions of SO_2 from its two smelters, effective January 1994.

- Ontario: In December 1985, Ontario enacted special regulations for the smelters owned by the International Nickel Company (Inco), Ltd. and Falconbridge in the Sudbury area.

  In addition, Inco and Falconbridge were required to research the feasibility of further reducing their SO_2 emissions.

  From 1985 to 1988, both companies were required to report every six months on progress in developing a program to meet the requirements of the regulations. By December 1988, as required, they outlined in detail how reductions would be achieved. Both companies are actively implementing emissions control programs and are expected to meet their respective targets for 1994.

Table 2.5.2 **Primary Metals Smelters in Eastern Canada: Kilotonnes of SO_2 Emissions per Kilotonnes of Metal Production and Metal Production in Kilotonnes (1)**

	Smelter	Primary Product	1970 Production	1970 SO_2/Tonne	1980 Production	1980 SO_2/Tonne	1987 Production	1987 SO_2/Tonne
(1)	Hudson Bay Mining & Smelting	Copper	46.4		65.8		68.0	
	Flin Flon, Manitoba (2)	Zinc	72.1	2.24	69.4	1.83	84.4	2.11
(2)	Inco Ltd. Thompson, Manitoba	Nickel	62.9	7.71	43.2	5.06	N/A	3.95
(3)	Inco Ltd.	Copper	150.7		135.6		120.0	
	Copper Cliff, Ontario	Nickel	180.5	4.92	122.0	2.38	113.4	2.12
(4)	Falconbridge Ltd.	Nickel	42.0		30.0		30.5	
	Sudbury, Ontario	Copper	5.0	7.28	24.0	2.30	12.7	1.65
(5)	Kidd Creek Mines Ltd	Copper	N/A	N/A		N/A	83.5	
	Timmins, Ontario	Zinc	N/A	N/A	101.6	0.01	114.4	0.02
(6)	Canadian Electrolytic Zinc (CEZ) (Noranda, Valleyfield, Quebec)	Zinc	168.0	0.02	347.0	0.03	220.0	0.02
(7)	Noranda Minerals Inc. Noranda Quebec (Horne)	Copper	191.0	3.24	201.0	2.75	158.0	2.73
(8)	Noranda Minerals Inc. Murdochville, Quebec	Copper	63.0	2.44	63.0	1.44	60.0	0.83
(9)	Noranda Minerals Inc.	Zinc	64.0	0.37	N/A		N/A	N/A
	Belledune, New Brunswick (3)	Lead	N/A		45.0	0.29	60.5	0.27

(1) Reference: The containment of SO_2 in the Canadian Non-Ferrous Smelting Industry - An update L. Buffa. Conservation and Protection, Environment Canada, Air and Waste Management Association, 82nd Annual Meeting & Exhibition, Anaheim, California, June 1989.

(2) The increase in SO_2 per tonne of metal protection from 1980 to 1987 is attributable to variability in the sulphur content of concentrates handled at this custom smelter.

(3) Since 1971, solely a lead producing smelter.

- Quebec : Under the federal-provincial SO_2 program, the first Quebec regulations were passed in early 1985 to deal with the two copper smelters at Noranda and Murdochville.

For the Noranda Mines Gaspe smelter at Murdochville, regulations limit SO_2 emissions to 275 kilograms per tonne of dry concentrate introduced into the process.

For any future smelters in Quebec, regulations limit SO_2 emissions to 4 percent of the total sulphur introduced into the process, and limit SO_2 emissions from the acid plant to 5 kilograms per tonne of acid produced. Regulations also impose a daily maximum for each plant's emissions and require the installation of continuous monitoring as well as production shutdowns or cut-downs to reduce sulphur discharges as required.

Table 2.5.3: Provincial Regulations Enacted to Meet the 1994 SO2 Reduction Target

	Annual SO2 Emissions (kilotonnes)	
	1980 (base case)	1994 (regulated limits)
Manitoba		
INCO (Thompson)	414	220
Hudson Bay Mining and Smelting (Flin Flon)	293	220
Ontario		
INCO (Copper Cliff)	1,155	265
Falconbridge (Falconbridge)	154	100
Quebec		
Noranda (Horne)	552	276
Mines Gaspe	91	65

2.5.1.2 INDUSTRY RESPONSE

The response of the non-ferrous smelting industry to emissions reduction regulations has varied on a plant-by-plant basis.

2.5.1.2.1 Inco Ltd., Thompson, Manitoba

Inco considered several potential approaches to contain SO_2 emissions at the Thompson operation, including sulphur recovery as sulphuric acid, liquid SO_2, and/or elemental sulphur; and capture of emissions with the Dual Alkali ammonia process. Analyses indicated that the remote location of the smelter would make the economic recovery of any saleable product impractical. It appears that the smelter will meet its 220 kilotonnes per year limit by removing more sulphur from the concentrate feed through the separation and rejection of the pyrrhotite component of the ore. While this step is generally the most economical means of sulphur control, the nickel content of the rejected pyrrhotite increases as percentages rejected go up, to a point where pyrrhotite rejection becomes economically unattractive.

The capital cost of implementing this option at Thompson is estimated at $60 million.

2.5.1.2.2 Hudson Bay Mining and Smelting, Flin Flon, Manitoba

At Flin Flon, Hudson Bay Mining and Smelting has developed a detailed plan for modernization. A new zinc pressure leaching plant will be constructed, and new equipment will be installed at the copper smelter. The zinc leaching plant will eliminate the traditional roasting of zinc ore and its resulting emissions of sulphur dioxide.

The copper smelter will be modernized by the incorporation of a Noranda Continuous Reactor that will make gases amenable to conversion to acid. This conversion will also permit the economical operation of the smelter at lower tonnages.

The capital costs of the modernization plan are estimated to exceed $130 million.

2.5.1.2.3 Inco Ltd., Copper Cliff, Ontario

In 1985, Inco Copper Cliff was ordered by provincial regulation to reduce its annual SO_2 emissions to 265 kilotonnes by 1994. At that time the plant was operating at close to capacity and releasing 685 kilotonnes per year of SO_2 (one third of its 1970 emissions).

The company responded by developing a bulk concentrate smelting process in which copper and nickel concentrates are smelted together in a flash furnace. The high strength gas that is liberated is then converted into sulphuric acid and liquid sulphur dioxide.

A new oversized acid plant is to be built at the smelter site with sufficient capacity to accommodate further sulphur dioxide production.

The new bulk smelting process, combined with the rationalization of the upstream mill (mainly through pyrrhotite rejection), will allow the smelter to meet the 265 kilotonnes per year target by 1994.

Inco has estimated the capital cost of this modernization program at $494 million, of which $69 million is slated for mill rationalization through the addition of new and larger Outokumpu flotation cells, while $425 million is slated for smelter additions. Inco has stated that financial assistance for capital construction will not be needed.

2.5.1.2.4 Falconbridge Ltd., Falconbridge, Ontario

The Falconbridge operation was completely modernized in 1978. A new smelter was constructed which incorporated fluid bed roasters, electric furnace smelting and a sulphuric acid plant.

That modernization resulted in a 50 percent reduction of emissions. Since 1982 the smelter has emitted less than its 1994 SO_2 target of 100 kilotonnes, as the plant has not operated at full capacity. To operate within the 100 kilotonne limit while at full operation, Falconbridge will employ a combination of techniques including pyrrhotite rejection, increased roasting and improved operation of electric furnaces. The capital cost of completing the additional changes necessary to meet the regulation has been estimated by the company at about $30 million; this excludes the cost of the original modernization. Falconbridge is also investigating the possibility of introducing an increased roasting in which more sulphur would be removed from the calcine as SO_2 for acid plant treatment. Implementation of this process would result in additional SO_2 emission reductions.

2.5.1.2.5 Noranda Minerals Inc., Noranda (Horne), Quebec

This Noranda operation is a custom smelter at which most ore is processed through a continuous reactor. The plant also uses one or two of its old reverberatory furnaces to treat concentrates which cannot be smelted in the continuous reactor.

Regulations require Noranda to capture 96 percent of the SO_2 from the gases leaving the continuous reactor. The company has been ordered to reduce its SO_2 emissions from 552 kilotonnes per year to 276 kilotonnes per year by 1990. In response, the company installed an acid plant with a capacity of 350 kilotonnes of sulphuric acid per year, at a capital cost of about $127 million. This plant has been in service since November, 1989. Currently, emissions from the reverberatory furnaces are discharged into the environment after treatment to remove particulate matter. However, under imposed provincial requirements, Noranda must make further changes which will entail closing the

reverberatory furnaces. This will result in a further 100 kilotonne reduction in SO_2 by 1995.

2.5.1.2.6 Noranda Minerals Inc., Murdochville, Quebec

This small smelter is expected to continue to operate as a custom smelter. It has an acid plant to process SO_2 emissions from three converters. The smelter's SO_2 emissions will be contained at or below the 65 kilotonnes per year set as its regulatory limit.

2.5.1.2.7 Financial Commitments at Canadian Smelters

Table 2.5.4 summarizes the capital costs of upgrades at eastern Canadian metal smelters to reduce emissions of SO_2.

Table 2.5.4 Capital Costs of SO_2 Controls at Non-Ferrous Smelters ($ Millions)

1- H.B.M.& S	$140.0 (1)
2- Inco, Thompson	$ 60.0 (2)
3- Inco, C. Cliff	$494.0
4- Falconbridge	$ 30.0
5- Noranda, Horne	$160.0
6- Mines Gaspe (Murdochville)	Not Available

(1) Estimate, 1988.
(2) Estimate, 1987.

2.5.2 ELECTRIC UTILITIES

Of the seven eastern provinces, Manitoba and Quebec are least reliant on fossil fuel electrical generation. The provincial utilities in Ontario, New Brunswick and Nova Scotia are the heaviest users of coal, and are thus faced with most of the SO_2 reduction burden from this sector.

2.5.2.1 ONTARIO HYDRO

Ontario Hydro (Hydro) is a provincially owned corporation which produces almost all of the province's electricity. Its projected 1993 generating capacity of 33 gigawatts is expected to be 23 percent hydro, 42 percent fossil-fuel-fired steam (78 percent of this coal-fired), and 35 percent nuclear (EMR, 1988).

Ontario's current Countdown Acid Rain Program (Regulation 281/87) requires Hydro to reduce its annual SO_2 emissions to 75 kilotonnes, and combined NO_x and SO_2 emissions to 215 kilotonnes by 1994. This represents a 60 percent reduction from Hydro's peak emission level in 1982, and must be maintained regardless of future growth in electricity demand.

In the period 1990 to 1993, Countdown Acid Rain requires Hydro to reduce its acid gas emissions from 430 kilotonnes per year to an interim limit of 280 kilotonnes.

To achieve these limits, Hydro plans to expand its use of low sulphur fuels, and to increase its efforts to reduce electricity demand through conservation, efficiency measures and non-utility generation.

In December, 1989 Hydro released a major demand/supply plan, "Providing the Balance of Power", which outlines anticipated growth in electricity demand and sketches various supply options.

Hydro intends to rely on a mix of electricity supply options including the rehabilitation of existing hydro and fossil plants, development of limited untapped hydro potential, purchases from neighbouring hydro-based utilities and in-province private power producers, conservation and demand management, and ultimately, the construction of major new generating plants. The preferred options for new generating plants include a mix of nuclear, combustion turbine, and integrated coal gasification combined cycle capacity. The additional thermal generating capacity component of the mix is expected to be required around the year 2000.

The 1989 plan outlines Hydro's strategy to deal with environmental requirements. To reduce $S0_2$ emissions Hydro intends to install flue gas conditioning systems at three coal-fired plants to enable them to burn low sulphur coal. By 1994, Hydro will retrofit two flue gas desulphurisation units at its Lambton plant and at other units thereafter, as needed. If the future growth of electricity demand is moderate, the need for an additional pair of scrubbers is forseen; in the event of hign demand, as many as 10 additional scrubbers would be required.

Hydro's plan to reduce its emissions by 1994 and maintain the 215 kilotonne cap will cost an estimated $2.7 billion (current year) through the year 2000.

Table 2.5.5 shows the acid gas limits for Hydro, together with recent SO_2 and NO emissions (the cap applies to total acid gas emissions including NO_x).

2.5.2.2 NEW BRUNSWICK POWER

New Brunswick Power (N.B. Power) is a provincial crown corporation which produces and distributes almost all of the electricity used in the province and which supplies, by

Table 2.5.5 - Ontario Hydro Acid Gas Emissions and Regulatory Limits

Emissions (Kilotonnes)

	1980	1982	1984	1986	1988
SO_2	396	450	444	270	321
NO (1)	66	81	75	50	60
Total Acid Gas	462	531	519	320	381

Regulatory Limits (Kilotonnes)

	SO_2	SO_2 + NO
1986-1989	370	430
1990-1993	240	280
1994 and after	175	215

(1) Note that NO_x limits elsewhere in this report are expressed as NO_2 whereas the Ontario Hydro regulation expresses NO_x as NO. 1 Kilotonne of NO is equivalent to 1.53 kilotonnes of NO_2.

underwater cable, over 80 percent of the electrical energy needs of Prince Edward Island. Most of N.B. Power's 3.5 gigawatts of capacity is thermal, and comprises 19 percent nuclear, 10 percent coal, 45 percent oil, and 26 percent hydroelectric (EMR, 1988). N.B. Power's system is heavily interconnected with three neighbouring provinces, and with utilities in the United States. It is, as a result, often called upon to assist other utilities facing shortages or outages. As well, N.B. Power has arrangements with neighbouring utilities in Canada and the United States to buy and sell considerable amounts of electricity; these can vary substantially from period to period. As a consequence, N.B. Power's fossil fuel use and the resulting emissions fluctuate significantly from year to year.

N.B. Power has developed an emission strategy within the eastern Canada control program to limit total annual emissions of SO_2 from thermal power plants to 130 kilotonnes.

N.B. Power currently operates four major thermal plants and is building a fifth at Belledune. The plan presented by N.B. Power entails the conversion of the 350 MW of oil-fired generation at Coleson Cove from 2.75 percent sulphur bunker "C" to "Orimulsion" (a water-bitumen mixture), with a 90 percent (nominal) efficient scrubber. Alternatively, low sulphur fuel could be burned at an annual cost of about $50 million. By 1994 a new

150-200 MW unit with 90 percent (nominal) efficient controls for SO_2 may be constructed to burn Minto high sulphur coal at Grand Lake. This unit will likely employ either fluidized bed or integrated coal gasification combined cycle technology; the cost will depend on the alternative chosen.

In addition, 200 MW of high sulphur Minto coal-fired generation at Dalhousie may be converted to low sulphur coal by 1994. A new 450 MW coal-fired unit with flue gas desulphurisation will be installed at Belledune by 1993. The capital cost of the latter is estimated at about $150 million, with annual operating and maintenance costs of $40 million.

Additional coal-fired capacity with stringent SO_2 controls will be added as required later in the decade .

Utilization of high sulphur Minto coal would be maintained at no more than 500 kilotonnes per year while projected exports of 4000 GWh in 1994 are expected to increase to 5000 GWh by the year 2000.

Table 2.5.6 presents N.B. Power's estimated SO_2 emissions under the proposed control scheme in kilotonnes for each major thermal plant.

Table 2.5.6 - New Brunswick Power SO_2 Emissions (Kilotonnes)

Plant	1988	1994/95
Coleson Cove	58.4	35.0
Dalhousie	61.1	37.0
Grand Lake	27.6	26.0
Courtenay Bay	16.2	8.0
Belledune	0.0	9.0
Other	0.6	1.0
	163.9	116.0

- The emissions objective for NB Power is 130 kilotonnes.
  (The SO_2 emission estimate for the Belledune plant reflects the installation of a scrubber.)

2.5.2.3 NOVA SCOTIA POWER CORPORATION

The Nova Scotia Power Corporation (NSPC) is a provincial crown corporation which produces and distributes almost all of the electricity consumed in the province. Of the total of about 2.0 gigawatts of installed generating capacity, 70 percent is coal-fired, 19 percent oil-fired and the balance, 11 percent, is mostly hydroelectric (EMR, 1988).

As its contribution to controlling $S0_2$ emissions in eastern Canada, NSPC has set a 1994 limit for its SO_2 emissions of 160 kilotonnes, within the overall provincial cap of 204 kilotonnes.

In 1980, NSPC emitted 122 kilotonnes of SO_2 from fossil fuel stations, while generating 6,321 GWh of electricity. By the year 2000, NSPC projects that its SO_2 emissions will be about 100 kilotonnes, despite a projected increase in fossil fuel generation to about 12,000 GWh of electricity. In other words, while production is expected to increase by about 90 percent, SO_2 emissions per unit of production will be almost halved. These results will be attained from both burning low sulphur coal and the installation of fluidized bed combustion units. The cost of this abatement program is estimated at $300 million over 20 years.

NSPC's plan to meet its 160 kilotonnes objective includes emission reductions at existing and new plants. Reductions at new thermal units will be accompiished, first by construction of a unit to burn low sulphur coal, then by the installation of fluidized bed combustion or other advanced coal burning technologies such as integrated coal gasification combined cycle units. Fluidized bed combustion technology will permit NSPC to capture over 90 percent of the sulphur from the about one million tonnes of coal mined annually at the province's Prince Mine. This high sulphur coal, now blended with lower sulphur coals from other mines, will be channelled through state-of-the-art fluidized bed combustion technology, and well over 50 kilotonnes of SO_2 will be removed as a result.

In order to address emissions from existing thermal units, NSPC is conducting research on effective and economically viable options to reduce emissions. These include conservation and efficiency improvements, better fuel quality, advanced coal cleaning, flue gas cleaning technology such as scrubbers and sorbent injection, and integrated coal gasification combined cycle plants.

2.5.2.4 NEWFOUNDLAND UTILITIES

Although two major electric utilities serve the province of Newfoundland, Newfoundland and Labrador Hydro (NLH), a provincial crown corporation, is the dominant electricity producer.

The provincial electric system is divided between the island of Newfoundland and Labrador. Over 95 percent of the electrical load is situated on the island, where most

economic hydro potential has already been developed. Most of the untapped hydro potential and existing production is located on the mainland in Labrador. On the island, 32 percent of the generating capacity is at a heavy oil-fired generating station at Holyrood (NEB, 1986). However, this plant normally satisfies less than 10 percent of the energy demand and is primarily used at peak times and in periods of low rainfall.

No large untapped hydro sites remain on the Island. As a result, future load growth will either have to be satisfied through a cable interconnection to Labrador where additional hydro sites exist, or by increasing reliance on fossil fuel generation. This latter option, and the control of the resulting SO_2 emissions, have not yet been addressed, although with current load growth projections new generating resources will probably be required by the mid-1990s. In the near term, SO_2 reductions are likely to be realized by burning low sulphur fuel oil at Holyrood.

2.5.2.5 PRINCE EDWARD ISLAND

The province's utility, Maritime Electric, is a private company which owns and operates about 122 megawatts of oil-fired capacity (EMR, 1988). For economic reasons, the province obtains in excess of 80 percent of its electrical energy from New Brunswick via underwater cable link. Maritime Electric's own capacity is used mainly for reserve, in case of cable failure and for emergencies; this arrangement is expected to continue for the foreseeable future.

2.5.3 OTHER SO_2 SOURCES

Major SO_2 sources which are not non-ferrous smelters or power plants relate primarily to the combustion of fossil fuels and to certain industrial processes. Some individual provinces have put in place reduction programs for these sources.

2.5.3.1 ONTARIO

As part of its Countdown Acid Rain Program, Ontario established regulations for Inco (Falconbridge), Algoma Steel (Wawa) and Ontario Hydro; all but the Wawa plant are discussed above. Other major SO_2 sources in the province include industrial facilities which consume large amounts of fossil fuels.

The Algoma Steel Corp., Wawa

The Algoma Steel Corporation operates an iron ore sintering plant at Wawa. Roasting the ore produces a clinker-like material containing about 49 percent iron, and releases SO_2 from the naturally occurring sulphur in the ore. The province reduced Algoma's annual SO_2 emission limit from 285 kilotonnes to 180 kilotonnes in 1986, and set a further limit of 125 kilotonnes for 1994.

In 1986, the plant's sinter production was reduced by 55 percent because of continuing economic difficulties in the North American iron and steel industry. At the same time, lower sulphur feed was used. As a result, annual SO_2 emissions have been running below the 1994 limit.

Technical abatement measures previously examined by the company will be pursued if economic conditions in the industry improve and plant operating levels are increased.

Fuel Combustion

To further reduce SO_2 emissions from fuel combustion, Ontario issued regulations limiting the amount of sulphur in fuel used in new or modified commercial and industrial boilers to 1 percent, unless an equivalent amount of SO_2 is removed from flue gases.

2.5.3.2 QUEBEC

In Quebec, other major sources of SO_2 apart from the primary metals sector are the pulp and paper industry, various industrial processes and miscellaneous fuel combustion techniques; these account for about 30 percent of emissions.

As of December 1989, the provincial utility, Hydro Quebec, has limited the sulphur content of the heavy fuel oil it utilizes at its Tracy power plant to 1.5 percent. This power plant is used in emergency situations, for example, the present low water levels at Hydro Quebec's hydro-electric dams that limit hydro generation. Costs of using low sulphur fuels have not yet been reported.

Quebec has set limits for SO_2 emissions from paper making processes and from pulping liquor recovery boilers. As well, the province is currently considering setting sulphur-in-fuel limits for heavy oil at 1.5 percent for new facilities and 2.0 percent for existing facilities. Current projections indicate that the province will meet its SO_2 emissions target in 1990.

2.5.3.3 NEW BRUNSWICK

Sources other than smelters and power plants in New Brunswick account for less than 10 percent of provincial SO_2 emissions. The major sources in this group are pulp and paper mills and industrial fuel combustion.

Ten of New Brunwsick's 11 pulp mill complexes have already modernized; the last is proceeding with construction projects which are expected to be completed in 1990-91. It is anticipated that this sector, despite growth, will maintain SO_2 emission levels of less than 15 kilotonnes per year without additional regulatory initiatives being required.

The Irving Oil Refinery in Saint John is meeting its SO_2 emission limit of 8 kilotonnes.

2.5.3.4 NOVA SCOTIA

In Nova Scotia, sources other than power plants account for a little over 20 percent of SO_2 emissions. The major emitters in this category are industrial fuel combustion and industrial processes.

Nova Scotia is reviewing those sources which may release over 100 tonnes of SO_2 per year to determine if additional control measures are needed.

The province's coal industry is investigating methods of improving coal and liquid fuels, and emerging technologies such as coal gasification are also being scrutinized. These programs have the potential to reduce SO_2 by substituting clean fuels for some of the high sulphur heavy oil and coal which are currently being used in some facilities such as industrial or commercial boilers.

2.5.4 SO_2 CONTROL OPTIONS

Table 2.5.7 summarizes the performance and costs of selected technologies which are described in more detail in Appendix 2A.2 of this report.

As explained in the foregoing sections, existing proven technologies to reduce SO_2 emissions from smelters, power plants and other sources have been applied or are expected to be implemented within a few years. By 1994, state-of-the-art technologies will be in place at Canadian non-ferrous smelters. Flue gas scrubbers, most likely of the wet limestone type, are planned for installation at several power plants. In Ontario, between two and twelve plants will be retrofitted with SO_2 controls. In New Brunswick, new coal-fired units will have scrubbers; one is now under construction at Belledune. For scrubbers in Ontario and New Brunswick, commercial gypsum recovery is being investigated.

While these control technologies are likely to continue to play a significant role, particularly for existing plants, they impose an energy penalty and present other environmental problems such as sludge disposal and the possibility of water contamination, although all these disadvantages can be mitigated. In the longer term, new control technologies which permit the simultaneous treatment of SO_2 and NO_x such as the NO_xSO or Copper Oxide Reduction processes may be employed.

The need to address issues such SO_2 in conjunction with other environmental concerns such as NO_x, global warming and requirements for better energy efficiency makes it most probable that new energy use technologies will replace current conventional modes of production. For example, the integrated gasification combined cycle combustion (IGCC) system for coal burning has the potential to provide many benefits to the utility industry. These include short lead time for construction, competitive capital cost and operational and planning flexibility. From an environmental perspective, the process also presents

Table 2.5.7 - Summary of SO_2 Control Measures

Sector/Technology	SO_2 Reduction Potential (percent)	Cost of SO_2 Reduction ($1988/Tonne)
Smelters		
Advanced Smelting & Processing (1) with Acid or Liquid SO_2 Production	>95	N/A (5)
Power Plants & Boilers		
• Coal Cleaning (2)	20-35	700 - 1200
• Advanced Coal Cleaning	45-60	600 - 1000
SO_2 Control		
• Scrubbers	>90	>500 (4)
• Sorbent Injection	70	>400 (4)
• Advanced Processes (3)	>90	
New Combustion Systems		
• Slagging Combustors	70-90	N/A
• Fluidized Bed	90	N/A
• Coal Gasification - Combined Cycle	>95	N/A

Notes:

(1) Advanced processes include pyrrhotite rejection, Zinc Pressure Leaching, Flash Smelting, and the Queneau Schumann Lurgi (QSL) process combined with acid or liquid SO_2 production.

(2) Coal cleaning also provides cost savings, particularly in transporting coal long distances because of the higher calorific value of the cleaned product.

(3) Advanced SO_2 control processes include Copper Oxide Reduction, the NO_xSO process and electron beam. These are not yet commercial.

(4) Cost is dependent on fuel sulphur content and plant capacity factor among other variables.

(5) Costs are site specific and depend on the ore type and other factors.

an opportunity to almost eliminate SO_2 and NO_x emissions, while improving overall energy conversion efficiency. IGCC is currently under active consideration by New Brunswick Power, Nova Scotia Power, Ontario Hydro and Trans-Alberta Utilities, among others. Other advanced combustion systems which promise simultaneous control of SO_2 and NO_x include slagging combustors and fluidized bed boilers; these processes are also under development by Canadian utilities.

Canadian industries, especially the metals and forest products industries, have been active in deploying new energy and resource efficient technologies. Many use electricity instead of much larger amounts of fuel-based energy, and hence result in overall emission reductions. As well, Canadian electric utilities are vigorously pursuing conservation and demand management programs as an integral part of their planning.

2.6 THE CANADIAN NO_x - VOCs CONTROL PROGRAM

As described earlier, the current federal-provincial NO_x-VOCs Management Plan is directed specifically at reducing the exposure of Canadians and the Canadian environment to excessive concentrations of ground level ozone, by reducing the emissions of the precursor pollutants, NO_x and VOCs. Reducing VOCs emissions is more difficult than reducing NO_x emissions, since VOCs include compounds from a large number of diverse sources. To deal with this problem, governments must enlist support from all those involved with handling VOC containing products. Reduction measures will have to include public education, product reformulation or substitution, and the recycling or destruction of some compounds.

2.6.1 PRE-1985 INITIATIVES

Vehicles are the most significant source of NO_x and HCs, and were targeted for major reductions beginning in 1971, paralleling similar actions in the United States. Vehicle standards and tests evolved year by year until 1975. In that year, the federal government passed comprehensive vehicle emission standards under the Motor Vehicle Safety Act which were further broadened and made more stringent in 1987 and 1988. Recently, the federal government has announced a further tightening of light duty vehicle emission standards similar to levels now in force in California. The major provisions now in force to control vehicle NO_x and HC emissions are shown in Table 2.6.1.

In 1981, the federal government published emission guidelines for new steam electric power plants. These set emission limits for NO_x at 258 nanograms per Joule (ng/J, heat input) for solid fuels, 129 ng/J for liquid fuels and 86 ng/J for gaseous fuels.

Limits on NO_x emissions, in the form of caps or source specific regulations, have also been imposed on power plants in the provinces of Quebec, Ontario, Saskatchewan, Alberta and British Columbia. As well, the federal government has published guidelines for NO_x emissions from its own boilers and furnaces and is currently developing much more stringent controls.

2.6.2 CURRENT NO_x-VOCs CONTROL INITIATIVES

Most of the current NO_x and VOCs reduction initiatives are being undertaken under the aegis of the federal-provincial Canadian Council of Ministers of the Environment (CCME). To date, major control initiatives for NO_x and VOCs have focused on light duty vehicles. The wide array of measures being considered reflects the variety of sources for NO_x and VOCs, the absence of major dominant point sources, and the number of different compounds which are implicated.

In 1988, federal regulations to phase out lead in gasoline by 1992 were advanced to December 1, 1990. The phase out will permit the use of three-way catalysts in vehicles

Table 2.6.1 Summary of Canadian Vehicle Emission Standards

Date/Application	Hydrocarbon Limits	Nitrogen Oxides Limits
1975		
Light Duty Vehicles	1.2g/km	1.9g/km
Evaporative	2.0g/test (c)	--
Heavy Duty Vehicles	(H.C. plus NOx)	6.0g/MegaJoule
1987/88		
Light Duty Autos	.25g/km	.62g/km
Light Trucks/ Medium Duty Vehicles	.5g/km	.75-1.1g/km
Evaporative	2.0g/test(s)	---
Heavy Duty Vehicles		
- Gasoline	.41-.71g/MegaJoule	2.2g/MegaJoule
Evaporative	3-4g/test(s)	---
- Diesel	.48g/MegaJoule	2.2g/MegaJoule

(c) Canister-type test (s) Shed-type test.

and improve the performance of existing and planned NO_x and VOCs control measures.

In 1988, the CCME ordered the development of a comprehensive management plan for NO_x and VOCs reduction by October 1990, in order to reduce ground level ozone to the national air quality objective of 82 ppb, and to meet international obligations agreed to in 1987.

A draft plan for consideration by the CCME was developed through extensive public consultation, and is scheduled to be released in the fall of 1990. Phase I, or the first edition of the plan proposes a variety of initiatives to reduce NO_x and VOCs emissions, particularly in those areas with the most serious problems. It also proposed that the plan be expanded by 1994 to meet stricter environmental quality objectives, and that those objectives and the means to attain them be determined in part by further studies. This work is now under way.

In coordination with this NO_x-VOCs initiative, Transport Canada and Environment Canada launched a joint program in April 1989 to put in place more stringent emission standards for internal combustion engines and their fuels.

The provinces are already implementing certain measures which are contained in the draft plan. For example, Ontario has reduced gasoline volatility in the summer months to an Reit Vapour Pressure (RVP) of 10.5psi. The extension of this measure to other jurisdictions such as the Greater Vancouver Regional District is being considered.

2.6.2.1 MOBILE SOURCES

In April of 1989, the federal departments of Transport and Environment launched a program to reduce, by up to 30 percent, emissions of NO_x and VOCs emitted from internal combustion engines (TC-EC, 1989). The program proposes to:

- adopt California-type vehicle emission standards,
- review emissions from marine, air and rail transportation sources,
- examine the need to regulate fuel quality, and
- develop appropriate control regulations.

The emission sources to be studied will include on-road vehicles, industrial engines, off-road applications and motor fuels.

<u>On-Road Vehicles</u>

On-road vehicles are those that are subject to regulation under the Motor Vehicle Safety Act (MVSA) and include motorcycles, light-duty vehicles, light-duty trucks, medium-duty vehicles and heavy-duty vehicles. The proposed new light-duty emissions standards would require a 60 percent reduction in NOx emissions from current standards enacted in 1987.

Table 2.6.2 provides additional details on the current and proposed vehicle NO_x and HC standards.

Table 2.6.2: Proposed Vehicle Emission Standards (2). (grams/kilometre)

	HC(1)		NOx	
	Current	Proposed	Current	Proposed
Motorcycles	-	.16	-	.25
Light Duty Cars	.26	.16	.63	.25
Light Duty Trucks	.5	.16-.20	.75-1.10	.25-.63
Medium Duty Vehicles	.5	.16-.31	.75-1.10	.25-1.50
Heavy Duty Vehicles	1.1-1.9	1.1-1.3	6.0	5.0

(1) Non-Methane HC
(2) Other provisions govern evaporative losses, carbon monoxide and particulate matter.
(3) Values are in grams per brake horse power-hour.

In addition to the above, measures to reduce refuelling and running loss emissions from on-road motor vehicles will be investigated. These include:

- the adoption of emission control component labels and warranties and hose routing diagrams,
- the adoption of on-board emission control system diagnostics,
- the assessment of inspection and maintenance programs, and
- refuelling vapour recovery systems.

Off-Road Vehicles and Industrial Engines

Preliminary data indicate that, by applying advanced emission control technologies, NO_x emission reductions of between 60 and 70 percent could be achieved for railway locomotives, and of between 38 to 71 percent for marine vessels. These emission reductions assume uncontrolled emission levels comparable to those from heavy-duty on-road vehicles. The feasibility of adopting these levels for railway locomotives and marine vessels, as well as emission controls for aircraft engines, will be addressed in the management plan . For engines used in construction, agricultural equipment, and in industrial applications, most emission control technologies developed for on-road vehicles should be adaptable.

Motor Fuels

Gasoline. Several properties of gasoline affect the quantity and type of pollution emitted when the fuel is transported, stored and consumed. The program will evaluate these for potential reductions.

Gasoline volatility: Gasoline with a higher volatility has a significantly increased potential to emit hydrocarbons, particularly in warm weather.

Aromatics: As well as playing a role in ozone formation benzene, toluene and xylene have been placed on the Priority Substances List under the Canadian Environmental Protection Act due to their toxicity. Gasoline-powered motor vehicles and evaporative losses from gasoline are the major source of these substances entering the environment.

Additives: Besides their potential effect on human health, gasoline additives can affect the performance of emissions control devices.

Evaporative emissions from gasoline marketing and distribution: Gasoline has a high vapour pressure, and the large volume of gasoline used accounts for most of the evaporative VOCs emissions from the transportation sector. These emissions can be reduced by changing the composition of gasoline to reduce its vapour pressure, by preventing escape of vapour during storage and transfer from the refinery to retail stations, by capturing vapour during vehicle refuelling using systems on the vehicle (onboard systems) or on the retail station fuel dispensing pumps, and by requiring more effective vapour control systems on gasoline-powered motor vehicles.

Diesel Fuel. Diesel fuel properties affect the quantity and type of pollution emitted from diesel engines and may interfere with the operation of emissions control devices. These will be reviewed as part of the current initiatives.

Sulphur content: The sulphur content of diesel fuel affects the quantity of particulates emitted by diesel engines. This may prevent the use of some control technologies, such as catalysts, or reduce the life expectancy of others, such as particulate traps.

Cetane: Cetane number is used as a measure the ignitability of diesel fuel. Cetane influences the formation of NO_x, HCs and particulates in engines.

T90: T90 is the temperature at which 90 percent of diesel fuel is evaporated during a standard distillation test; temperatures higher than T90 can increase particulate emissions.

Fuel composition: Fuel composition affects emissions and the durability of emissions control hardware.

2.6.2.2 STATIONARY SOURCES

The March 1990 NO_x-VOC Draft Management Plan contains a number of initiatives which are targeted at stationary sources of NO_x and VOCs. For NO_x, these include more stringent emission standards for new and some existing power plants and industrial boilers, as well as for new stationary engines and combustion turbines. For VOCs, the large number of dissimilar sources precludes broad-based measures. Instead, a wide array of measures target various source categories such as refineries, fuel distribution and marketing, surface coatings, dry cleaning and miscellaneous solvent use.

2.6.3 NO_x AND VOCs CONTROL OPTIONS

Table 2.6.3 summarizes a number of control measures and technologies for NO_x and VOCs now being considered as part of the plan to reduce emissions of these pollutants (LRTAP. S.C., 1990). These technologies are described in more detail in Appendix 2A3.

Table 2.6.3 Summary of NOx & VOCs Control Measures

Sources/Control Technology	Maximum Reduction Potential (1) (percent) NOx	VOCs
A - Mobile Sources		
° Light Duty Gasoline Vehicles (LDGV)		
- Improved Catalysts and air fuel mixture control, exhaust gas recirculation.	–	–
- Better Evaporation Systems	90	90+
- On Board Refuelling Emission Control	–	–
- Lower Gasoline RVP	–	–
° Heavy Duty Gasoline Vehicles (HDGV)	–	–
- Same as LDGV	–	–
° On-Road Diesel Engines (ORDE)	50	0
- Turbo charging, aftercooling, better injection, exhaust gas recirc.	45-55	38
° Off-Road Diesel Engines (Construction, Agriculture) (Forestry, Mining)	N/A	N/A
° Other Diesel Engines (Locomotives, etc.)	N/A	N/A

B- Major Stationary Combustion Sources	Maximum Reduction Potential (3) (percent) NOx	VOCs	Average Cost Effectiveness (2) $1987/tonne ($ 1987/kw) NOx	VOCs
° Electric Utility Boilers				
- Combustion Controls	5-80+	—	30-95	—
- Flue Gas Controls (SCR, NCR)	70-90		1500 +	
- Fluidized Bed Combustion (FBC)	50-80	=	(1500+)	=
- Integrated Gasification Combined Cycle (IGCC) (4)	90-95+	—	(1200-2000)	—
° Industrial Boilers				
- Combustion Controls	5-80+	—	50-95	—
- Flue Gas Controls	70-90+	—	1500 +	—
° Combustion Turbines				
- Steam injection	70+	—		—
- Water Injection	70+	—		—
- Catalytic Exhast Gas Treatment	90+	—		—

NOTES:

(1) Emission reduction potential from uncontrolled case.
Note that much of the baseline inventories and costs have yet to be determined.

(2) "Combustion Controls" includes fuel and air mixing techniques to reduce NOx emissions, such as low-NOx burners, low excess air, overfire air, air and fuel staging etc. These modifications to existing boilers may in some cases, increase unburned hydrocarbon (VOC) emissions. These modifications may also yield small improvements in energy efficiency.

(3) "Flue Gas Controls" includes post-combustion techniques to reduce NOx emissions, such as Selective Catalytic Reduction (SCR); (SCR) will result in emission of ammonia.

(4) Fluidized Bed Combustion (FBC) and Integrated Gasification Combined Cycle (IGCC) will also reduce SO2. IGCC will yield better cycle efficiency than conventional plants.

Table 2.6.3: Continued

- Large Stationary Sources: VOC Emissions (1)	Maximum VOC Reduction Potential (percent)	Average Cost Effectiveness ($1987/tonne)
° Crude Oil Production		
Fugitive Emissions	70	1 000
Transfer Emissions	75	N/A
° Petroleum Refining		
Fugitive Emissions	80	410
Storage Emissions	90	230
° Gasoline Distribution and Marketing		
Storage & Transfer	85 (2)	100 (2)
Delivery	85	170
Refuelling	80	3 000
Volatility	>95	100
° Organic Chemical Manufacturing		
Process Emissions	95	330
Fugitive Emissions	55	1 540

(1) Excludes miscellaneous sources such as Plastics Processing, Pulp and Paper, Wood Burning, Paint Application, Adhesives, Inks, Degreasing, Dry Cleaning, Consumer Products, Pest Control Products, Solvent Use, for which cost data and reduction potentials have yet to be determined.

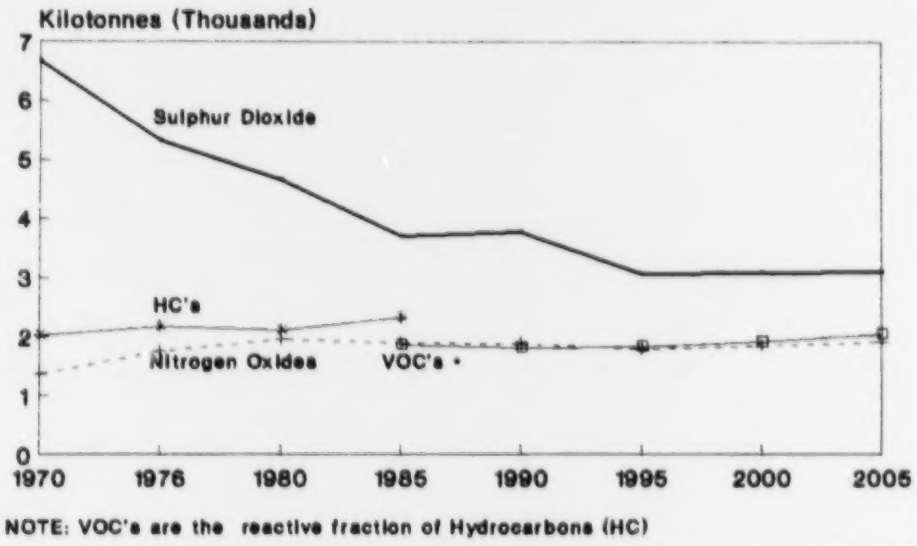
(2) Average value for a series of measures.

2.7 EMISSIONS AND CONTROL MEASURES IN THE 1990s

2.7.1 OVERVIEW OF EMISSION TRENDS

The last two decades have seen a continuing decline in Canadian emissions of SO_2, while emissions of NO_x and VOCs have remained relatively constant, despite a substantial increase in vehicle use and economic activity. These trends, illustrated in Figure 2.7.1, are largely the result of measures taken by governments and industry in the 1970s and 1980s.

Fig. 2.7.1: Canadian Emissions Trends: SO_2, NO_x, VOC's 1970 - 2005



• NOTE: VOC's are the reactive fraction of Hydrocarbons (HC)

2.7.2 PROJECTED EMISSIONS IN CANADA

The projections for SO_2, NO_x and VOCs reflect the best information available to Environment Canada as of March 1990. They include only emissions reduction programs that had been committed as of that date, and exclude new but as yet uncommitted initiatives. The latter include the recently announced more stringent vehicle emission standards (California standards), proposed but as yet uncommitted control initiatives by

provincial governments, and the federal-provincial management plan for NO_x and VOCs, now under development.

The national emission projections for the next 15 years show that, for SO_2, NO_x and VOCs, the declining trend will bottom out and emission rates will resume a slow climb beginning early in the next century. This is largely due to the expected increase in the number of sources linked to projected overall economic growth.

Inventories of, and projections for, NO_x and VOCs are being reviewed and may be revised. The year 1985 is chosen as the base year because it is the most recent year for which a detailed emissions inventory has been compiled. The data presented in Figures 2.7.2 to 2.7.7 correspond to tables numbered 2.7.1 to 2.7.6 in Appendix 2A1.

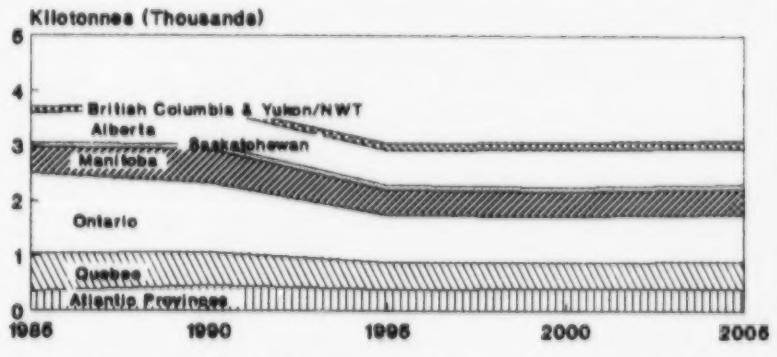
2.7.2.1 PROJECTED SO_2 EMISSIONS

Figures 2.7.2 and 2.7.3 illustrate projected emissions of SO_2 by region and by sector for the period 1985 to 2005.

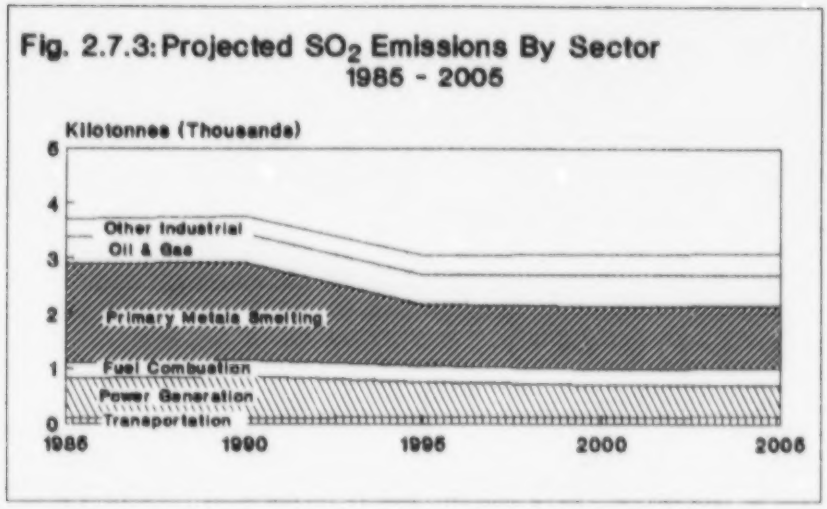
In that time, emissions are expected to fall about by 20 percent, from 3.7 megatonnes in 1985 to about 3.1 megatonnes in 1995. This is a reduction of 34 percent from the 1980 level of 4.6 megatonnes. The largest single-province reductions are expected in Ontario, the greatest producer of SO_2.

In the eastern provinces, provincial regulations and permits will result in reductions of major source SO_2 emissions under the various federal-provincial agreements. However, in the western provinces, increases in SO_2 emissions will occur if no control programs are undertaken. The post-1994 control program will address these issues.

Fig. 2.7.2: Projected SO_2 Emissions By Region 1985 - 2005



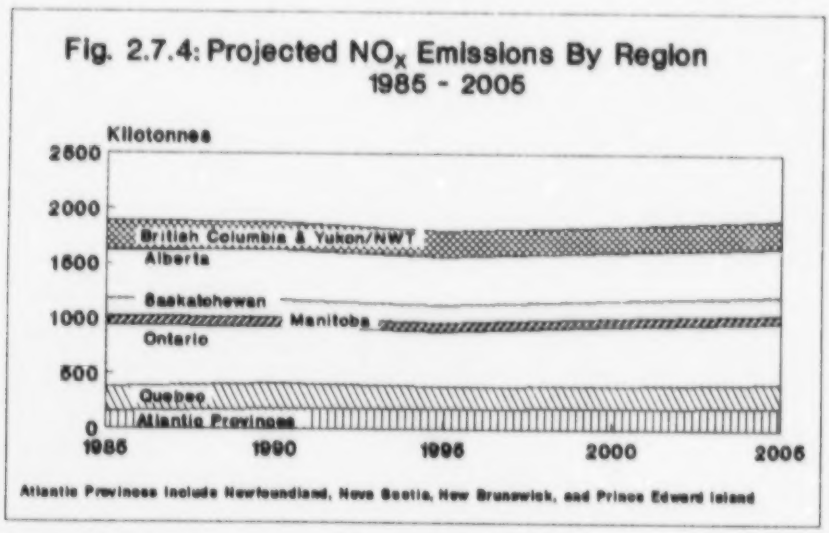
Atlantic Provinces include Newfoundland, Nova Scotia, New Brunswick, and Prince Edward Island

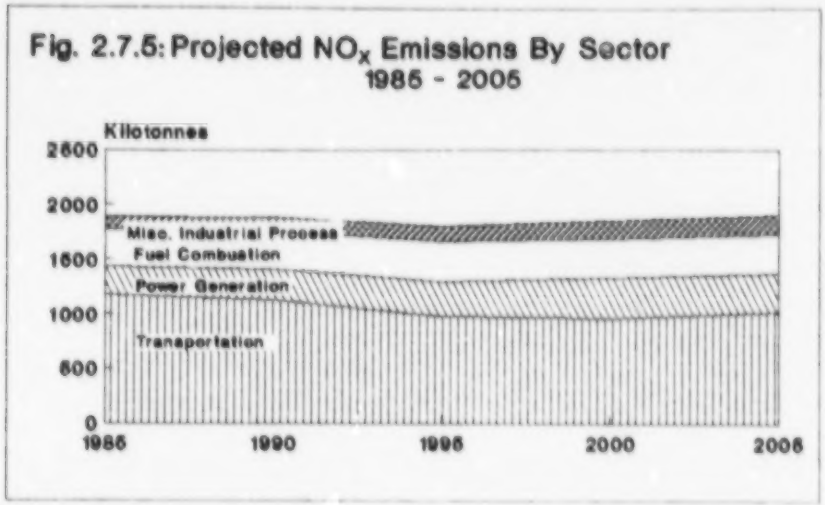


2.7.2.2 PROJECTED NO_x EMISSIONS

Canadian emissions of NO_x are illustrated in Figures 2.7.4 and 2.7.5. These show that, due to existing vehicle emission standards, NO_x emissions will decline until the year 2000, but begin to increase thereafter, unless further actions are taken. Projected levels for the mid-1990s are less than the goal established in the Sofia NO_x protocol, which set a 1994 upper limit on Canadian NO_x emissions at 1987 levels.

Because of the projected long-term increase in emissions additional reduction measures will be required if Canada is to continue to reduce NO_x emissions and meet its international obligations.





2.7.2.3 PROJECTED VOCs EMISSIONS

Figures 2.7.6 and 2.7.7 show the projected emissions of VOCs from 1985 to 2005. It is estimated that emissions will increase from 1.8 megatonnes in 1985 to 2.0 megatonnes in 2005.

Most of the emissions and the increases are in the provinces of Ontario, Quebec, Alberta and British Columbia, the provinces with large and growing vehicle populations and significant petrochemical and industrial activity.

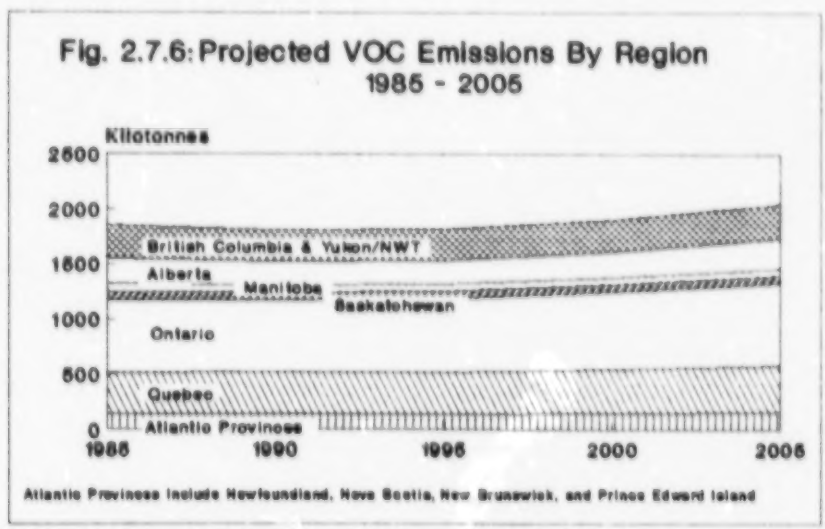
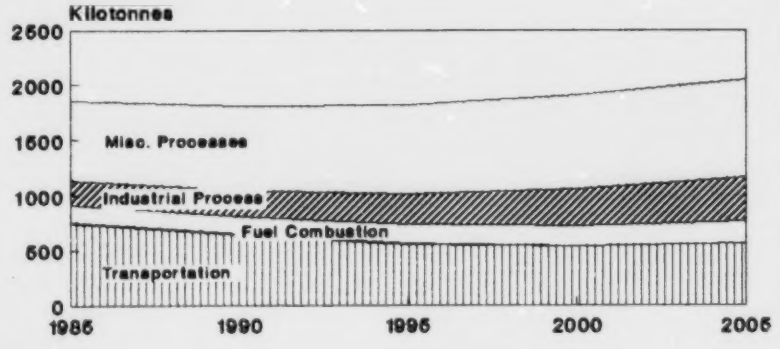


Fig. 2.7.7: Projected VOC Emissions By Sector
1985 - 2005



2.8 FUTURE DIRECTIONS

As demonstrated by this Report, Canadian acid rain causing emissions are being abated and are declining at the rate necessary to meet the goals of the eastern Canada acid rain control program. The flow of Canadian transboundary emissions to the United States is also being reduced. The program is on target for meeting the 1994 deadline.

However, a number of unresolved air quality problems face Canada as it approaches the new century. Despite the success of the current program, unless further controls as described in this report are applied, acid causing emissions are expected to rise in the future as population densities and industrial activities increase. It is predicted that ground level ozone and urban smog will increase for much the same reasons. At the same time, toxic air pollutants and global warming will demand greater attention both domestically and internationally. These emissions will have to be controlled by regional and national programs.

Canada will need to expand and adapt its atmospheric pollution control programs to address these problems. Control of SO_2, NO_x and VOCs will need to be integrated with the control of greenhouse gases and airborne toxic substances, as Canada's program to meet the total challenge of air pollution issues evolves. Care will have to be taken to ensure that control measures directed against one pollutant do not exacerbate the situation with regard to others. Scientific research, monitoring and the development of new technologies will need to continue in order to meet the demands of the future.

As the current SO_2 agreements expire in 1994, and as other air pollution issues are addressed, the federal and provincial governments will examine various options to implement environmental control measures in the most economically efficient way. Further federal-provincial agreements, regulations, and technology transfer will remain useful tools. Consensus on clearly stated objectives, timetables and mechanisms for the regular reporting of progress should continue to be features of any new programs.

"Market measures" such as the use of permits, taxes and incentives are likely to play an increasingly important role in the fight against air pollution. The setting of limits for pollutant emissions for existing facilities, and the use of best available control technology economically achievable for new facilities, will preclude the establishment of pollution havens within Canada, and ensure environmental protection. New power plants in Alberta, Saskatchewan, New Brunswick and Nova Scotia are already meeting the National Guidelines for New Stationary Sources of Thermal Power Generation. These guidelines require the use of state-of-the-art technology to control emissions of SO_2, NO_x and particulates.

Internationally, Canada will continue to recognize the transboundary and global nature of air pollution, and continue to fulfil its international responsibilities. It is expected that Canada will participate in the negotiation of international agreements with the Economic Commission for Europe on VOCs and SO_2 within the next few years. Canada will

continue its vigorous efforts to press for a joint acid rain agreement with the United States.

The challenge for the 1990s and the twenty-first century will be to build upon present efforts to improve air quality, to protect human health and the natural environment for this and future generations by putting into practice the principles of sustainable development.

APPENDICES

APPENDIX 2A1 SUPPLEMENTARY DATA TABLES

(The following tables complement figures in the main text)

Table: 2.3.1

Sulphur Dioxide Emissions In Canada by Province
1970 - 1985
(Kilotonnes)

	1970	1976	1980 (actual)	1980 (baseline)	1981	1982	1983	1984	1985
Canada	6677	5320	4644	4516	4291	3612	3625	3957	3704
Newfoundland	54	53	56	59	41	42	36	38	43
Prince Edward Island	9	9	5	6	3	3	2	2	2
Nova Scotia	144	171	193	219	193	179	175	201	170
New Brunswick	133	162	220	215	221	206	172	162	138
Quebec	1309	1145	1098	1085	1002	932	792	737	693
Ontario	3226	2227	1764	2194	1645	1142	1275	1572	1457
Manitoba	760	590	484	738	421	362	408	466	469
Saskatchewan	56	53	55	-	56	82	97	111	86
Alberta	624	536	600	-	543	504	513	517	539
British Columbia	359	371	167	-	163	157	152	148	105
Yukon/NWT	3	3	2	-	3	3	3	3	2

NOTE: Baseline emissions are corrected to reflect existing regulatory caps in place prior to the eastern Canada plan. These baseline levels are the reference for the acid gas control program in Eastern Canada.

Table: 2.3.2

Nitrogen Oxides Emissions In Canada by Province
1970 - 1985
(Kilotonnes)

	1970	1976	1980	1981	1982	1983	1984	1985
Canada	1365	1755	1959	1907	1896	1884	1871	1887
Newfoundland	27	31	36	35	34	33	33	34
Prince Edward Island	6	8	7	6	6	6	6	6
Nova Scotia	56	81	86	67	71	73	76	74
New Brunswick	39	53	58	56	52	48	49	46
Quebec	259	323	331	298	272	263	257	223
Ontario	425	526	565	602	588	585	550	558
Manitoba	61	81	80	78	75	79	76	82
Saskatchewan	95	126	125	114	134	134	150	156
Alberta	225	305	430	421	413	408	415	440
British Columbia	155	206	225	214	235	239	243	253
Yukon/NWT	17	15	16	16	16	16	16	16

Note: Nitrogen oxides are expressed as NO_2

Table: 2.3.3

Hydrocarbon Emissions In Canada by Province
1970 - 1985
(Kilotonnes)

	1970	1976	1980	1985	(VOCs) 1985
Canada	2017	2167	2098	2315	1855
Newfoundland	25	39	30	38	36
Prince Edward Island	8	8	7	12	11
Nova Scotia	63	79	71	74	52
New Brunswick	46	54	51	53	45
Quebec	437	475	404	398	372
Ontario	655	667	623	676	653
Manitoba	95	90	80	73	71
Saskatchewan	149	141	118	124	84
Alberta	273	323	427	392	229
British Columbia	259	286	281	467	295
Yukon/NWT	7	5	6	8	7

Note: Volatile organic compounds exclude methane and non-reactive chlorinated compounds.

Table: 2.7.1

Sulphur Dioxide: Projected Emissions in Canada by Province: 1985 - 2005 (Kilotonnes)

			Committed Targets(1)			
	1985	1990	1994	1995	2000	2005
Canada	3704	3762	2474	3052	3070	3099
Newfoundland	43	62	45	45	45	45
Prince Edward Island	2	3	5	3	4	4
Nova Scotia	170	196	204	182	173	167
New Brunswick	138	198	185	167	181	185
Quebec	693	594	600	490	480	503
Ontario	1457	1282	885	864	840	865
Manitoba	469	602	550	449	448	449
Saskatchewan	86	90	-	92	89	87
Alberta (2)	539	623	-	642	684	660
British Columbia	105	110	-	116	124	132
Yukon/NWT	2	2	-	2	2	2

(1) The 1994 committed targets are the levels agreed to by the seven eastern provinces as part of the Acid Rain Control Program and are referenced to 1980 baseline levels. The actual target is 2300 kilotonnes; the 174 kilotonnes of unallocated reductions are to be agreed to by October 1990, to achieve the 2300 kilotonnes target in 1994. Beyond 1994, for the seven eastern provinces, the upper ceiling remains at the 1994 committed target level.

(2) Does not include approximately 20 kilotonnes from gas well testing.

Table: 2.7.2

Sulphur Dioxide: Projected Emissions in Canada by Sector 1985 - 2005 (Kilotonnes)

	1985	1990	1995	2000	2005
Transportation	95	103	115	128	147
Power Generation	738	764	643	579	553
Fuel Combustion (1)	279	297	293	298	321
Primary Metals Smelting	1781	1754	1119	1124	1129
Oil & Gas (2)	502	524	530	571	563
Other Industrial (3)	309	321	352	371	387
Total Canada	3704	3762	3052	3070	3099

(1) - "Fuel Combustion" Excludes Power Generation

(2) - "Oil & Gas" includes Tar Sands, Refining and Natural Gas Processing

(3) - "Other Industrial" includes Iron Ore Mining, Pulp and Paper, Incineration and Miscellaneous other sources.

Table: 2.7.3

Nitrogen Oxides: Projected Emissions in Canada by Province
1985 - 2005
(Kilotonnes)

	1985	1990	1995	2000	2005
Canada	1888	1878	1797	1841	1903
Newfoundland	34	35	33	34	36
Prince Edward Island	6	6	5	5	5
Nova Scotia	74	81	78	79	83
New Brunswick	46	64	69	75	81
Quebec	223	227	205	207	218
Ontario	558	525	504	540	554
Manitoba	82	81	74	72	77
Saskatchewan	156	159	158	158	166
Alberta	440	455	441	438	436
British Columbia	253	228	212	213	225
Yukon/NWT	16	17	18	20	22

Notes: Nitrogen oxides are expressed as NO2.

Table: 2.7.4

Nitrogen Oxides: Projected Emissions in Canada by Sector (1)
1985 - 2005
(Kilotonnes)

	1985	1990	1995	2000	2005
Transportation	1180	1122	976	961	1020
Power Generation	248	288	319	364	352
Fuel Combustion (2)	346	350	368	365	357
Misc. Industrial Process (3)	113	117	133	152	175
Total Canada	1887	1877	1796	1842	1903

(1) Nitrogen oxides are expressed as NO2.

(2) "Fuel Combustion excludes Power Generation but includes natural gas processing

(3) "Miscellaneous Industrial Processes" includes Iron Ore mining, Pulp and Paper, Incineration etc.

Table: 2.7.5

Volatile Organic Compounds: Projected Emissions in Canada by Province 1985 - 2005 (Kilotonnes)

	1985	1990	1995	2000	2005
Canada	1855	1809	1822	1905	2047
Newfoundland	36	35	37	45	49
Prince Edward Island	11	11	11	11	11
Nova Scotia	52	50	48	49	51
New Brunswick	45	45	45	46	48
Quebec	372	381	384	398	421
Ontario	653	655	670	704	753
Manitoba	71	65	60	58	60
Saskatchewan	84	75	70	70	74
Alberta	229	211	214	233	267
British Columbia	295	274	276	284	305
Yukon/NWT	7	7	7	7	8

Note: "Volatile Organic Compounds" include reactive hydrocarbon compounds and exclude methane and certain chlorinated compounds.

Table 2.7.6

Volatile Organic Compounds(1): Projected Emissions in Canada by Sector (1) 1985 - 2005 (Kilotonnes)

	1985	1990	1995	2000	2005
Transportation	749	645	557	532	561
Power Generation	3	3	3	3	3
Fuel Combustion(2)	161	161	175	189	200
Industrial Process	223	239	280	335	395
Misc. Processes(3)	717	761	806	846	889
Total Canada	1853	1809	1821	1905	2048

(1) "Volatile Organic Compounds" include non-methane reactive compounds only.

(2) "Fuel Combustion" excludes Power Generation but includes natural Gas Processing

(3) "Miscellaneous Process" includes incineration, slash burning, solvent use, fuel, marketing, etc.

APPENDIX 2A2 SO_2 CONTROL TECHNOLOGIES

2A2.1 NON-FERROUS SMELTERS

In Canada, ores of metals such as zinc, copper and nickel occur primarily as metal sulphides. After extraction, ore is ground and sent to a mill where the desired minerals are concentrated by various physical and chemical processes. The resulting concentrate is then sent to a smelter to be roasted, smelted, converted and refined. Each step improves purity by removing sulphur as SO_2 and other impurities as slag.

Several approaches are available to control SO_2 emissions from metals smelting operations. These fall into two general categories: the selection of process options which prevent SO_2 production, and the removal of SO_2 and its subsequent recovery as sulphuric acid, liquid SO_2 or elemental sulphur.

2A2.1.1 PROCESS OPTIONS

Separation and Removal of Sulphide Minerals

The iron sulphide mineral pyrrhotite is a significant source of sulphur in copper and nickel ores. When pyrrhotite is rejected, however, there is also a loss of associated metals; this limits the amount of pyrrhotite that can economically be separated prior to smelting. Pyrrhotite rejection is widely practised at mills where more than 50 percent of ore sulphur is removed.

Zinc Pressure Leaching

Zinc pressure leaching can be applied at those smelters currently producing zinc by conventional roast-leach-electrowin operations. Instead of undergoing the conventional roast-leach step, zinc sulphide concentrate is pressure leached in autoclaves, to form zinc sulphate. Zinc is recovered by electrolysis, and elemental sulphur from unreacted sulphides is recovered without the production of SO_2. One smelter (Cominco at Trail, British Columbia) is already using the process while another (Hudson Bay Mining and Smelting at Flin Flon, Manitoba) is planning its use.

2A2.1.2 REMOVAL OF SO_2 FROM EXHAUST GASES

Production of Sulphuric Acid

In this approach, exhaust gases are first cleaned of impurities and then directed to an acid plant where, after a series of chemical operations, SO_2 is converted to sulphuric acid. Acid plant technology is considered to be a fully established process. Seven smelters now have acid plants: Inco and Falconbridge, Sudbury; Kidd Creek Mines, Timmins; Noranda, Gaspé; Noranda, Valleyfield; Noranda, Horne; and Noranda, Belledune.

Production of Liquid SO_2

To produce liquid SO_2, the SO_2 exhaust stream is cleaned of impurities and then compressed and liquefied, in a process similar to acid production. Only two metal smelters (Inco, Copper-Cliff and Cominco, Trail) produce liquid SO_2 at this time.

New Technologies

In order to produce sulphuric acid and liquid SO_2, the SO_2 content of exhaust gases must be high. Research has focused on obtaining higher concentrations of SO_2 in gas streams. The flash smelting of combined copper/nickel concentrates and the Queneau Shumann Lurgi (QSL) process are two techniques used to obtain these higher concentrations.

Flash smelting: In the flash smelting process, copper and nickel ore concentrates are combined and smelted together in a flash furnace. The principal feature of flash smelting is that the normally separate processes of roasting and smelting are combined. The process produces a lower volume of gas with a higher concentration (up to 80 percent) of SO_2 which can then be efficiently captured. Inco is in the process of installing flash smelting at its Copper Cliff smelter by 1994.

QSL: The QSL process is a continuous, direct lead-making process which incorporates two different pyrometallurgical operations in one smelting vessel. The advantages of QSL include reduced capital and operating costs, low levels of SO_2 and particulate emissions and the production of a high strength SO_2 gas stream. This can efficiently be captured for sale as sulphuric acid or liquid SO_2. The QSL process has been installed at Cominco Ltd's lead smelter at Trail, British Columbia.

2A2.2 POWER PLANTS AND BOILERS

2A2.2.1 COAL CLEANING

Sulphur is present in coal in several forms. The "total sulphur" content of typical eastern United States and Canadian coals ranges from 1 percent to 8 percent. A combination of pyritic and organic sulphur commonly constitutes over 98 percent of the total sulphur in any coal.

The removal of the pyritic sulphur from coal prior to use is widely employed in North America. Coal cleaning processes are utilized to produce low-sulphur low-ash coal, for which there is a growing market. Advanced methods may soon be available for addition to existing coal cleaning processes and/or facilities to improve their overall sulphur removal effectiveness. Other benefits of coal cleaning include enhanced calorific value and reduced ash content and hence lower transportation costs and less ash to dispose of after combustion.

Conventional Coal Cleaning

Depending on the size distribution of the coal used, existing conventional gravity-based multistage cleaning technologies are capable of physically removing from 30 to 50 percent of the pyritic sulphur and 30 to 70 percent of the ash-forming minerals from coal, at process and product loss costs which are acceptable to coal users.

Organic sulphur, which is a chemical constituent of coal, cannot be removed by existing conventional gravity-based cleaning processes.

Numerous "advanced" coal-cleaning processes are being developed in the United States, Canada and worldwide. These processes can be classified into two categories: advanced physical and chemical-biological.

Advanced Physical Processes

Coal, pyrite and ash-forming mineral particles all have differing specific gravities, electrical or magnetic characteristics, and affinities for water. Advanced physical processes are designed to utilize such differences. Although these processes can produce coal with a significantly lower pyrite and ash content than can be obtained by existing conventional processes, they cannot reduce the organic sulphur content of coal. The leading advanced physical cleaning generic processes being tested or demonstrated include:

- oil agglomeration,
- micro-bubble flotation,
- column flotation,
- true heavy media bath,
- true heavy media cycloning,
- electrostatic separation, and
- magnetic separation.

Depending on the nature of the coal being tested, results to date suggest that, under certain conditions, several of these generic processes are capable of economically removing up to 60 to 90 percent of pyritic sulphur and similar quantities of ash-forming minerals.

Although not designed for sulphur removal, several physical processes are being investigated and/or developed to reduce the moisture and ash contents and increase the calorific value of low sulphur, low rank, western coals. These have the potential to make more western coals available for use in the eastern Canadian market, and displace the higher sulphur fuels now used there.

Chemical/Biological Processes

Many chemical and biological coal cleaning processes have been developed. A number of these have been shown to be capable of removing or reducing both pyritic and organic sulphur. However, these innovative processes all have drawbacks that appear to be substantially greater than those of conventional multi-stage and advanced physical processes.

2A2.2.2 CONTROL OF SO_2 DURING AND AFTER COMBUSTION

A number of processes are available to capture SO_2 during and after combustion. Some of these are also able to reduce the formation of NO_x and are reviewed in more detail in Appendix 2A3.

Wet Flue Gas Desulphurisation

- Lime/Limestone Systems: In lime/limestone systems, boiler flue gases are ducted into a large chamber at atmospheric pressure and sprayed in a scrubber with a calcium reagent in the form of either lime or limestone. There, the SO_2 reacts with the calcium to form calcium sulphate which is then removed for disposal or utilization. The choice of sorbent is usually decided by the costs of raw materials and the options available for the disposal of waste products or the use of by-products. The higher percentage of active calcium per ton of lime permits the use of smaller process vessels and less costly systems for that mineral than for limestone. However, the costs of preparing lime may offset the apparent advantages of lower process costs.

  Until recently, scrubber sludge has not usually been regarded as commercially useful, and in North America was therefore dumped as landfill, sometimes together with fly-ash from ash collection systems. Great care should be taken in the preparation of such landfill sites to avoid contamination of adjacent groundwater. Such by-products can, however, be processed into commercial quality gypsum (CaSO4). In Japan and West Germany, calcium sulphate by-product has been used as commercial quality gypsum to make construction wall board and other products.

- Magnesium Oxide (MgO) Process: Commercially, the process has had no major continuous commercial application in electricity generating systems, although three full-scale units were built in the United States.

- Sodium Sulphite Process: Wet scrubbers using sodium sulphite as the SO_2 reaction medium seem to be initially attractive because of the regenerability of the reagent and the production of by-product sulphur or sulphuric acid. Sodium carbonate or sodium hydroxide is used to convert sodium salt products, formed by SO_2 reactions with the original reagent, to reconstituted sodium compounds;

these can then be used to restart the cycle. The regenerated by-products include concentrated liquid SO_2 which can be sold or used to produce sulphuric acid.

This "Wellman-Lord" process, as it is generally known, has had more success than the magnesium oxide process. Its application is still very restricted, however, because of process system costs, the possible contamination of groundwater by spent reaction products and its technical complexity.

- Dual Alkali Wet Scrubbing: A potential disadvantage of some wet scrubbing systems is their tendency to form deposits (scale) on the internal surfaces of equipment from the precipitation of calcium compounds. This scaling can seriously interfere with operations, and may require excessive maintenance.

  To avoid this, dual alkali scrubbers can use sodium as a hydroxide or sulphite to remove SO_2 from gases and form other sodium compounds in the scrubber. These are removed from the scrubber and regenerated by the addition of slaked lime and/or limestone into the original scrubbing solution of sodium hydroxide. The end product is either commercial quality gypsum or waste calcium sulphate for landfill.

Dry Flue Gas Desulphurisation

A potential drawback of some wet desulphurisation systems is the necessity of disposing of very large quantities of unusable wet sulphate sludge. To avoid this, it is possible to use the heat of flue gases to evaporate water from the sulphate reaction products in the scrubber vessel. The resulting product is a dry powder, easily stored as calcium sulphite or sulphate. For high sulphur coal which requires extensive SO_2 removal, the process is not as economical as wet limestone systems, since it needs more expensive lime to operate efficiently.

- Sorbent Injection (SI) Processes: Wet or dry scrubbers require the use of complex equipment which can entail heavy maintenance costs. To provide an alternative and potentially less expensive method, substantial effort has gone into the development of simple systems to inject powdered lime or limestone, either dry or in the form of water slurries, into the upper region of a boiler, where it reacts directly with SO_2.

  For some low sulphur coals, or in situations not requiring high SO_2 removal efficiency, these direct injection methods may provide adequate SO_2 reduction, though they are generally chemically inefficient and require substantially more quantities of sorbent than wet scrubbers to achieve moderate reductions. As well, this technique may require additional costs to dispose of greater amounts of waste material.

Other Combustion and Emission Control Technologies

A number of new technologies for SO_2 reduction exist which have not yet been as fully investigated as those described in the proceeding sections. Such technologies are listed below; where there is potential for overlapping benefits from the concomitant removal of NO_x and VOCs, such technologies are also considered in Appendix 2A3.

- Slagging Combustors: In a slagging combustor, pulverised coal and an alkali compound are introduced into a cylindrical chamber in a swirling pattern. The coal sulphur reacts with the alkali compound and it, with the ash, is removed as a molten slag. NO_x emissions may also be controlled by measures such as staged combustion.

- Copper Oxide Reduction: Copper oxide reduction is a joint SO_2-NO_x control technology in which copper oxide is used in a fixed or fluidised bed reactor. The copper oxide reacts with SO_2 to form copper sulphate, which is then used as a catalyst with ammonia to reduce NO_x. SO_2 reduction potential is reported to be about 90 percent.

- NO_xSO Process: The NO_xSO process is a combined SO_2 and NO_x reduction scheme in which sodium oxide is used on alumina in a fluidised bed absorber. SO_2 is captured in the form of sodium sulphate. This in turn is regenerated to produce hydrogen sulphide, which is ultimately converted to elemental sulphur.

- SULF-X Process: This process uses iron oxide in a complex absorber system to control both SO_2 and NO_x emissions; sulphur is recovered as elemental sulphur. The process is claimed to achieve SO_2 reductions of approximately 90 percent.

- Electron beam irradiation: In electron beam irradiation, flue gases pass through a chamber where they are exposed to an electron beam. This, in the presence of ammonia or lime, converts the SO_2 to usable chemicals. The process is claimed to reduce SO_2 emissions by about 80 percent.

Fluidised Bed Combustion:

- Atmospheric Fluidised Bed Combustion (AFBC): In fluidised bed combustion, fuel is burned in a bed of granular material which is fluidised by the injection of air from below the bed.

  There are two major types of AFBC systems: bubbling-bed and circulating-bed. They differ in the location of their heat absorption surfaces, feedstock particle size, and throughput velocities. The potential SO_2 control efficiency for the circulating bed technique is in excess of 90 percent.

- Pressurised Fluidised Bed Combustion (PFBC): Similar to the AFBC process, in PFBC systems combustion takes place in a bed of particles of solid fuel and sorbent fluidised by a stream of air and combustion gases, but under pressure. As with AFBC, the SO_2 removal potential is in excess of 90 percent.

  Advantages of PFBC over AFBC include higher overall thermal efficiency (40 percent), a smaller sized unit because of its higher operating pressure, and a greater potential for the modular fabrication and construction of system components.

- Integrated Gasification Combined Cycle (IGCC): IGCC systems use electricity in a complex process whereby SO_2 can be almost completely eliminated from exhaust streams and NO_x can also be reduced to very low levels. The major advantages of the technology are its modular nature, short lead time for installation and potential for significantly improved overall thermal efficiency.

APPENDIX 2A3 CONTROL MEASURES FOR NO_x AND VOCs

2A3.1 MOBILE SOURCES

Light duty gasoline vehicles (LDGVs)

For LDGVs, reducing "tailpipe" HC and NO_x emissions by the implementation of "California standards" would require higher precious metal content in three-way catalysts, better air-fuel mixture control, and perhaps the use of a by-pass catalyst for a few types of vehicles. Better air-fuel ratio control can be achieved through changes in engine computer software and through greater use of fuel injection; the other requirements would probably be passed along via higher prices to consumers. The estimated potential emissions reductions are 90 to 95 percent for NO_x and HCs, respectively.

In-use inspection and maintenance (I/M)

The emissions control equipment originally installed on new vehicles is designed to function within specification for the "useful life" of a vehicle; useful life is currently defined as 5 years or 50,000 miles. For the latest model vehicles in particular, if a vehicle is maintained in accord with the manufacturer's recommended schedule and not misfuelled, its equipment should operate efficiently for considerably longer than 50,000 miles, thus keeping NO_x and HC emissions low.

Clinics and surveys conducted in both Canada and the United States have shown that anywhere between 20 and 50 percent of light duty vehicles may have emissions in excess of regulated standards. These higher emissions result from the rigors of on-road driving, lack of sufficient maintenance and tampering with vehicle emission control systems.

These problems can be dealt with effectively by provincial regulations to prohibit tampering and encourage proper maintenance. Such programs would need to be enforced with some or all of the following measures: a pro-controls, anti-tampering publicity campaign; a dealer-mechanic education program; a dealer-mechanic enforcement program; and an in-use inspection and maintenance program. Regular compulsory I/M inspections are now required in over 50 major urban areas in the United States. An I/M program should include an inspection on vehicle resale as a minimum, and could also require a compulsory vehicle inspection on an annual or other basis.

The potential emission reductions from these measures is estimated at 5 percent for NO_x and 25 percent for VOCs.

Heavy duty gasoline vehicles (HDGVs)

Gasoline powered heavy duty vehicles utilise exhaust gas recirculation and ignition timing modifications to reduce NO_x emissions. HDGVs with a gross vehicle weight rating of up to 14,000 lbs usually have an oxidation catalyst to meet the more stringent hydrocarbon

to 14,000 lbs usually have an oxidation catalyst to meet the more stringent hydrocarbon and carbon monoxide limits set for their category of vehicle. Three-way catalysts are not yet sufficiently resistant to high temperatures of HDGV engines, however, and so cannot be applied to these vehicles at this time. Therefore, HC standards for heavy duty trucks are more lax than for their light duty counterparts.

Diesel engines (On-road, Off-road, Locomotives)

Current emission control technology is similar for both on-road and off-road diesel engines and for diesel locomotives. It involves the optimization of engine design and operation rather than the application of new emission control technologies. Because some of the changes used to reduce NO_x emissions from diesel engine operation also increase particulate emissions. NO_x emission regulations for diesel engines must be combined with particulate regulations.

NO_x and particulate control options for diesel engines include turbocharging and aftercooling, higher pressure induction, exhaust gas recirculation, retarded injection timing and fuel rate control.

Future diesel engines will have after-treatment devices such as filters and catalysts, and will require low sulphur diesel fuel to operate properly.

2A3.2 BOILERS

The NO_x controls available for industrial, commercial and utility boilers may be conveniently grouped into 3 categories: combustion modification, flue gas treatment and new combustion techniques.

Combustion Modification

Combustion modifications include the installation of new burners or a variety of techniques to control fuel and air mixing in conventional boilers.

- Low excess air: This involves reducing the amount of excess air supplied to a boiler to aid combustion. Incomplete combustion and increased smoking can occur if the level of excess air is too low.

- Overfire air: This involves the redirection of some combustion air to a region above the top row of burners. Again, incomplete combustion and increased smoking may occur.

- Air staging: Used to improve the efficiency of the overfire air technique. With advanced air staging, up to 50 percent of combustion air is redirected above the

low-NO_x burners. Typical overfire air concepts redirect less than 25 percent of combustion air.

- Low-NO_x burners: These burners are specially designed to control air and fuel injection to a boiler so that the initial mixing of the fuel and combustion air is limited, thereby creating a lower temperature combustion zone and less NO_x formation. They can operate as conventional burners on new boilers as well, if the boiler has been designed for their combustion regime. Some problems have been experienced with carbon carry-over (incomplete combustion) in retrofits.

- Fuel reburning: This involves the diversion of about 10 percent of the primary fuel, or the introduction of a secondary fuel such as natural gas, into a region above the main burners so that a fuel-rich zone is created. The special conditions so created in this secondary combustion zone convert some of the NO to molecular nitrogen, thereby averting further oxidation which changes NO into NO_2. Use of a low fuel-nitrogen secondary fuel such as natural gas tends to be more effective than reburning with coal or oil.

- Exhaust gas recirculation: In this approach, a portion of a boiler's flue gases are recirculated back to the burner to dilute combustion air, thereby quenching the flame and reducing the formation of NO_x. This measure can be applied to some existing and new units.

- Slagging combustors: For NO_x control, hot gases are injected into a boiler to complete combustion in a manner which lengthens the normal combustion process and thereby reduces NO_x formation. As described in Appendix 2A2, the process also allows for the simultaneous removal of SO_2.

Flue Gas Treatment

Flue gas treatment techniques are designed to remove NO_x from exhaust gases after combustion, in addition to preventing their formation in the first place. Many techniques are available, although some are still experimental.

- Non-catalytic reduction: In-furnace non-catalytic reduction involves the injection of urea (N_2H_4CO) directly into a furnace. The urea reacts with NO_x to produce molecular nitrogen and water vapour. This process has significant NO_x reduction potential. However, as with sorbent injection to control SO_2, this process can result in increased particulate collection and waste disposal problems.

- Selective catalytic reduction (SCR): SCR systems involve the use of a catalyst and the injection of ammonia in a device installed on the flue gas discharge system of a boiler. The system converts nitrogen oxide to elemental nitrogen and water. It is commonly used for NO_x control in Germany, Austria and Japan.

- Copper oxide reduction (CuO): Copper oxide (CuO) is used dry in a fixed bed or fluidised bed reactor. The CuO reacts with SO_2 in the flue gas to form copper sulphate. Ammonia is added as in selective catalytic reduction, and the copper sulphate becomes a catalyst for the selective reduction of nitrogen oxide to molecular nitrogen.

Other combustion techniques:

The following technologies combine NO_x and VOCs control with SO_2 reduction, and so alter traditional approaches to pollution abatement. They offer new opportunities for controlling emissions and increasing combustion efficiency. Their applications in SO_2 control are discussed in Appendix 2A2.

- Atmospheric fluidised bed combustors generally operate at a lower peak furnace temperature than conventional boilers or furnaces. As well, their flame residence time is comparatively lengthy, allowing for the more complete burnout of less reactive fuels. These characteristics make this technology an attractive option to allow for the use of low reactivity fuels and still achieve low NO_x emissions.

- Integrated gasification combined cycle (IGCC): IGCC systems integrate and synchronize the coal gasification and electricity generation processes. Generally, hot gases from a coal gasifier are used to fuel a combustion turbine. Combustion turbines are available with low NO_x combustors; in addition, steam or water injection can be used with combustion turbines to achieve low NO_x emission levels. Newer techniques such as direct oxygen combustion and the reuse of flue gas in a heat recovery boiler also offer significant opportunities for achieving low NO_x emission levels.

2A3.3 OTHER STATIONARY COMBUSTION SOURCES

Reciprocating compressor engines

Present emissions reduction techniques for reciprocating compressor engines consist of a combination of operational adjustments and hardware additions. Operational adjustments include changing the air-to-fuel ratio, retarding ignition timing, and de-rating the engine. Hardware additions include exhaust gas recirculation, redesigned combustion chambers and devices to reduce manifold air temperature.

Available NO_x control technology for reciprocating engines entails the installation of catalytic exhaust gas treatment systems which reduce NO_x to molecular nitrogen. In the future, there is a possibility that some gas fired reciprocating compressors could be replaced by electrically driven compressors. This would shift part of the emission burden from the natural gas industry to the electric power industry.

Combustion turbines

The majority of combustion turbines in service today were not specifically designed to minimize NO_x emissions. Furthermore, because of increased turbine efficiency and power, contemporary combustion turbines tend to produce more NO_x emission than older units of comparable size.

In practice, combustion turbine installations can usually meet stringent standards without any need for extensive controls, although the technology to either retrofit or build new units with significantly reduced NO_x emissions is well established. Technologies for reducing combustion turbine NO_x emissions include water or steam injection and dry low NO_x combustors. Selective catalytic reduction has also been used to achieve very stringent NO_x control on some installations.

2A3.4 STATIONARY VOCs SOURCES

These sources are widely distributed throughout the economy and therefore require a wide spectrum of VOCs control or containment measures.

Fuel marketing

- Marketing terminals - installation of internal floating tank roofs. Internal floating roofs can reduce VOCs emissions from fixed roof tanks by 96 percent, and could be made mandatory for marketing terminal tanks.

- Marketing terminals - vapour recovery. This consists of condensing, adsorbing or incinerating the vapours emitted during fuel transfer operations. It is estimated that 79 to 90 percent of vapours can be recovered by this technology.

- Vapour balancing at bulk plants and service stations. This entails the installation of a closed system between tank trucks or rail cars delivering gasoline and gasoline storage tanks. The goal of the system is to prevent the escape of vapours during the delivery process.

  This control technique requires that marketing terminals and refineries be equipped with vapour recovery systems. The theoretical efficiency of this technique is 95 percent. In-use efficiency, however, would probably be lower.

- Gasoline volatility reduction. This control option would require that refineries reduce the volatility of gasoline from May to September. A volatility reduction of 17 kpascals (or 2.5 PSI) would result in an 8 to 10 percent lowering of annual VOCs emissions from the gasoline marketing and distribution sector.

Petroleum refineries

Emissions of VOCs at petroleum refineries can come from numerous sources; fugitive emissions may represent 50 percent of total refinery emissions.

Controlling these emissions requires better maintenance of valves, flanges, compressors etc. Other measures which can be used include:

- floating covers on waste-water separators,
- secondary seals on external floating roofs,
- internal floating roofs in volatile hydrocarbon service, and
- vapour recovery for gasoline loading at refineries.

Petrochemicals

There is, at present, very little information available on the controls in place in the petrochemical industry. The sources of such emissions are very similar to those in the petroleum refining sector - process emissions, fugitive emissions and emissions from the storage and handling of feedstocks and products. Control technologies would likely also be similar: capture and destruction or recovery of process emissions; improved maintenance programs and the adoption of management practices to reduce fugitive emissions; reduction of storage losses by the installation of floating roofs on tanks storing volatile organics; and the recovery of loading emissions when necessary. On this basis, it is estimated that a theoretical emissions reduction of up to 90 percent from uncontrolled levels is possible.

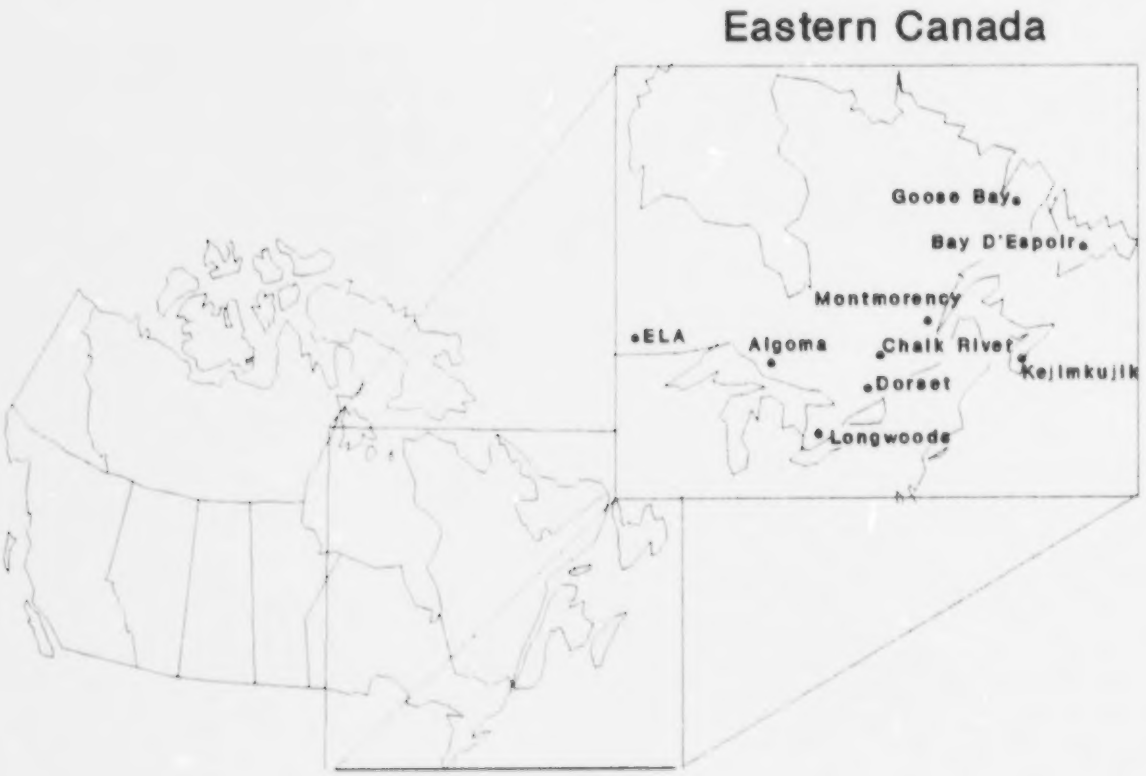
Miscellaneous Solvent Use

Solvents and volatile hydrocarbons come from many sources; these include paint applications, degreasing and cleaning, dry cleaning, and printing. The substitution of non-volatile solvents such as water in problem products, or the reduction or elimination of solvent use altogether, for example by the use of powder coatings, hold promise for reducing many of these emissions.

APPENDIX 2A4

MAP OF SELECTED SULPHATE MONITORING SITES IN EASTERN CANADA

Selected Sulphate Monitoring Sites In Eastern Canada



REFERENCES

Dan, T.: Canadian Urban Monitoring Programs for SO_2, NO, and VOC, paper presented at the Seminar on the Contemporary Oxidant Problem, Vancouver, B.C., February 27-28, 1989.

LRTAP. S.C., 1990: Management Plan for Nitrogen Oxides and Volatile Organic Compounds, First Edition, Draft, Federal/Provincial Long Range Transport of Air Pollutants Steering Committee, March 1990.

Lippmann, M.: Health Effects of Ozone: A Critical Review, APCA Journal, Vol. 39, No. 5, pages 672-695, May 1989.

EMR, 1988: Electric Power in Canada 1988, Electrical Energy Branch, Energy, Mines and Resources Canada, Catalogue No. M23-7/1988E.

NEB, 1986: Canadian Energy Supply and Demand 1987-2005, National Energy Board of Canada, September 1988.

O.H., 1989: Providing the Balance of Power, Ontario Hydro Demand/Supply Plan Report, 1989.

MOI, 1983: Impact Assessment, Work Group 1 Final Report, United States - Canada Memorandum of Intent on Transboundary Air Pollution, March 1983, Page 1-6.

TC-EC, 1989: A Plan to Identify and Assess Emission Reduction Opportunities from Transportation, Industrial Engines and Motor Fuels, Transport Canada, Environment Canada, March 1989, TP977BE.

I.C.J., Corfu Channel Case, 1949, International Court of Justice .4; Trail Smelter Case, 1941, 35 Am. J. Intil. 684; Lake Lanoux Arbitration, France Vs. Spain, 1957, 24 I.L.R. 101.